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USAAVLABS TECHNICAL REPORT 69-68

INTEGRAL HELICOPTER CARGO RESTRAINT SYSTEM

By

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October 1969

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-68-C-0038

THE BOEING COMPANY, VERTOL DIVISION

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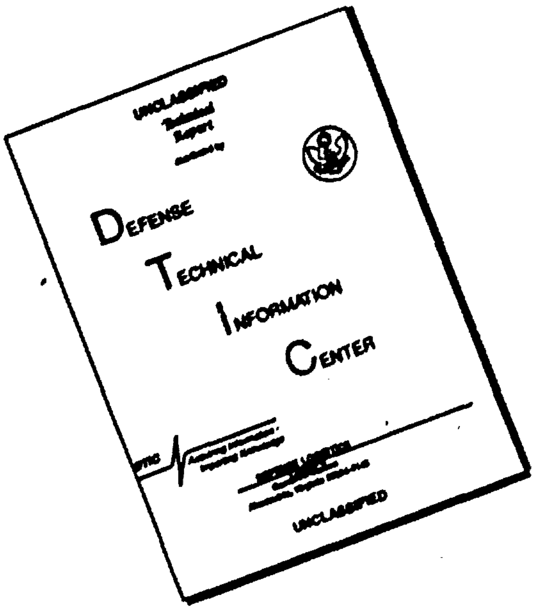

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This report ~~was prepared by~~ Boeing-Vertol Division under the terms of Contract DAAJ02-68-C-0038. It presents the engineering concepts and preliminary design of an integral helicopter cargo restraint system that may be incorporated in present or future helicopters.

Candidate cargo restraint systems and energy absorber concepts were formulated and evaluated both qualitatively and quantitatively to meet crash survivability design objectives. A theoretical analysis of restraint fittings, cargo floor, and fuselage frame of a CH-47 helicopter was conducted to ascertain their compatibility with dynamic loads.

The object of this contractual effort was to achieve a more effective cargo restraint system which would limit cargo movement in all directions by energy absorption in order to prevent injuries to crewmen or passengers in a potentially survivable crash.

In general, the design solution in this program is sound and reasonable.

The conclusions contained herein are concurred in by this command.

Project 1F162203A254
Contract DAAJ02-68-C-0038
USAAVLABS Technical Report 69-68
October 1969

INTEGRAL HELICOPTER CARGO RESTRAINT SYSTEM

Final Report

By

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Prepared by

The Boeing Company, Vertol Division
Philadelphia, Pennsylvania

for

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

SUMMARY

The purpose of this study is to formulate an effective cargo restraint system for the present CH-47 helicopter, and, as applicable, for new helicopter design. The restraint system will incorporate an energy absorption concept as an integral part of the helicopter structure, and is to be capable of restraint in all directions to prevent injuries to crew or passengers in a potentially survivable crash. This is accomplished by the following:

1. Reviewing related cargo restraint technology pertinent to energy absorbing (or dissipating) materials and devices, accident survivability data, and Vietnam cargo tiedown experience.
2. Formulating design criteria, in order to meet design objectives, consisting of dynamic (and static) load factors at the 90th percentile level of survivability and a combat crash survivability tiedown envelope using minimum restraint techniques.
3. Conducting a dynamic analysis of the CH-47 cargo supporting structure to determine its capability to restrain cargo during survivable crash conditions.
4. Formulating candidate cargo load-attenuating restraint systems for integral helicopter use.
5. Evaluating candidate cargo restraint systems and energy absorber concepts, both qualitatively and quantitatively.
6. Comparing existing Army restraint systems, experimental 5,000-pound (5K) and 10,000-pound (10K) capacity load-limiter systems, and the candidate load-limiter systems on a yardstick of correct restraint methods. The comparison included a system-effectiveness evaluation and a determination of crash survivability levels for both standard technical manual tiedown procedures (Figure 1) and combat operations (Figure 2).

The restraint system recommended for the CH-47 helicopter consists of 7,500-pound (7.5K) capacity load-limiting energy absorbers and low-elastic cargo tiedown devices. The energy absorbers are tube-ball type, capable of an 8-inch stroke, and are to be permanently installed in the airframe under the floor. To insure an improvement in crash survivability and a decrease in potential fatalities, it is further recommended that correct tiedown procedures be practiced and stressed in the field.

Preliminary design of a retrofit kit for the proposed restraint system is completed, and cargo load attenuation concepts for future aircraft design are discussed.

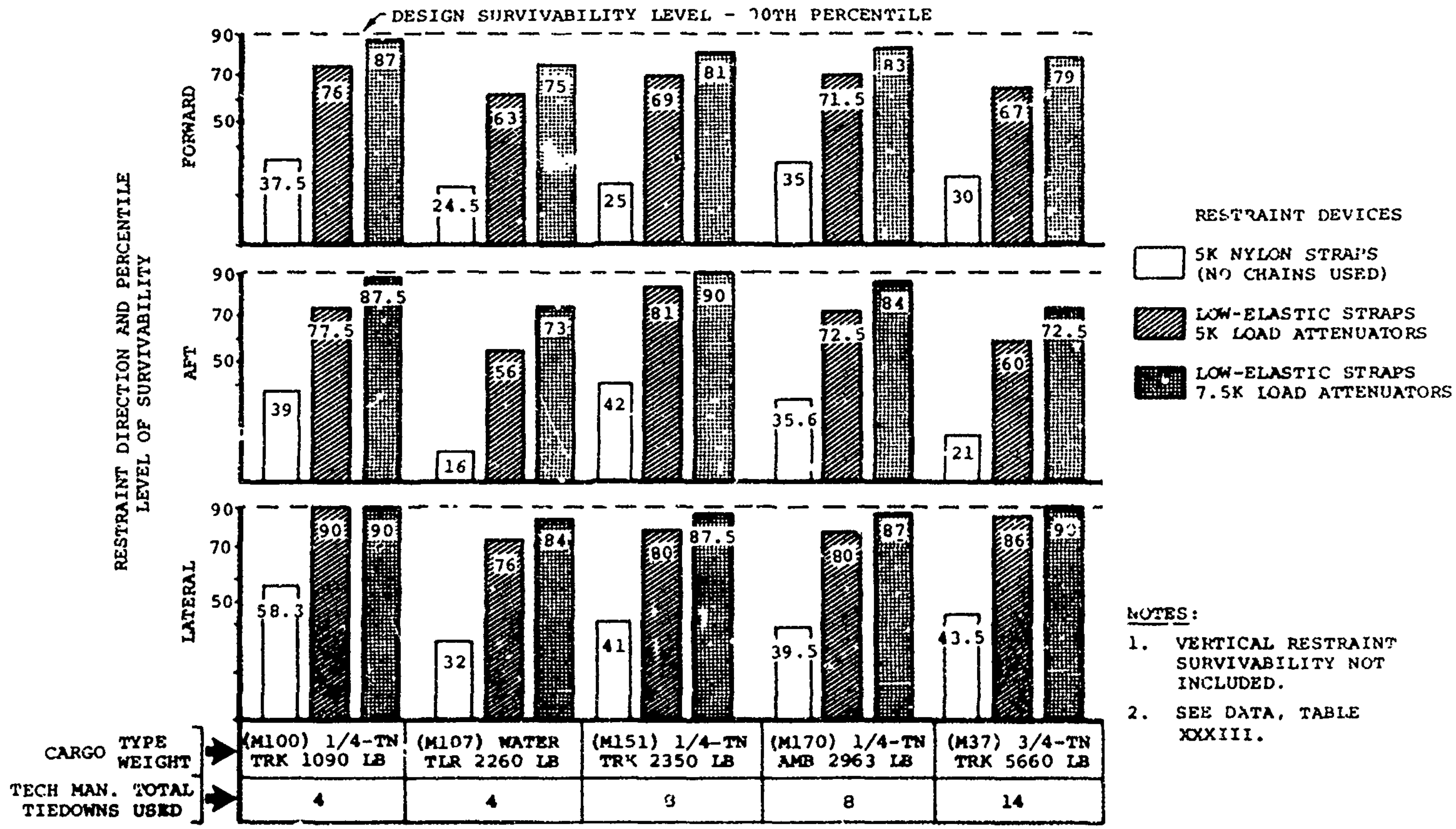

Figure 1. **Standard Cargo Restraint. Comparison of Percentile Levels of Survivability for Three Restraint Systems, Based on Dynamic Criteria, Using Technical Manual Tiedown Procedures.**

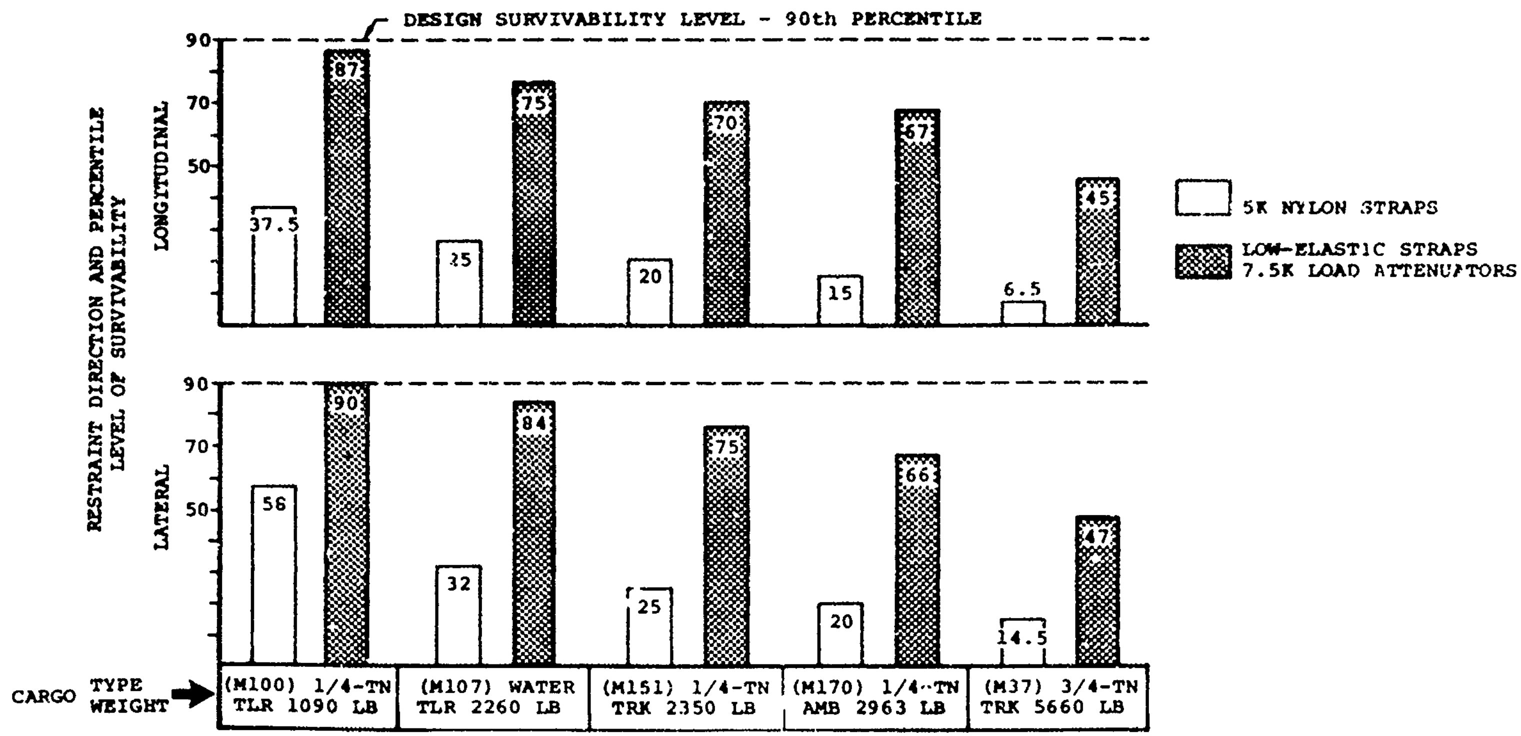

Figure 2. Combat Cargo Restraint. Comparison of Percentile Levels of Survivability for 7.5K Load Limiter and 5K Nylon Strap Systems, Based on Dynamic Criteria, Using Four Tiedown Devices for Multidirectional Restraint.

FOREWORD

Development of the integral helicopter cargo restraint system described in this report was performed by the Vertol Division of The Boeing Company, under Contract DAAJ02-68-C-0038, Project 1F162203A254, for the U.S. Army Aviation Materiel Laboratories (USAAVLABS), Fort Eustis, Virginia.

The developmental work was conducted in three phases, each phase being contingent upon the approval of the Contracting Officer: Phase I, Technology Review and System Definition; Phase II, Analysis and System Selection; and Phase III, Preliminary Design.

The authors gratefully acknowledge the guidance and assistance of Max Bryan and Jules Vichness of USAAVLABS, and David F. Thompson of Boeing. Manufacturers listed in the front of the report supplied useful information about restraint equipment.

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LIST OF SYMBOLS AND ABBREVIATIONS

A/C	aircraft
BL	butt line
EAD	energy absorbing device
F_{TU}	ultimate tensile strength
HOGE	hover out of ground effect
K	1,000-pound (capacity)
ksi	1,000 pounds per square inch
LL	load limiter
LRU	line replaceable unit
MTBR	mean time between replacement
N.A.	neutral axis
NP	normal power
POL	petroleum, oil, and lubricant
UTS	ultimate tensile strength

LIST OF MANUFACTURERS AND ORGANIZATIONS

Abbreviation	Name
-	Acme Products Division Interlake Steel Corporation 135th Street and Perry Avenue Chicago, Illinois
-	Aeroquip Corporation 1130 Maynard Road Jackson, Michigan
AAE	All American Engineering Company Du Pont Airport, Box 1247 Wilmington, Delaware
ACED	Air Crew Equipment Department Naval Air Development Center Philadelphia Naval Yard Philadelphia, Pennsylvania
ARDE	ARDE Company 580 Winters Avenue Paramus, New Jersey
AVSR	Dynamic Science Division Marshall Industries (formerly Aviation Safety Engineering and Research) 1800 West Deer Valley Drive Phoenix, Arizona
-	Menasco Manufacturing Company 805 South Fernando Boulevard Burbank, California
MRI	Mechanics Research Inc. 650 North Sepulva Boulevard El Segundo, California
-	Peck and Hale, Inc. Box 368 Sayville, Long Island, New York
VZA	Van Zelm Associates Entwistle Corporation 1475 Elmwood Avenue Providence, Rhode Island

1. INTRODUCTION

The goal of this contract is to devise an energy absorption system that may be incorporated in present or future helicopters for the restraint of cargo during crash events. Contract design objectives are listed in Section 3.1.

A helicopter cargo restraint system must prohibit cargo movement in all directions in order to prevent injuries to crew or passengers in a potentially survivable crash. Field experience with present-day restraint systems has indicated that a need exists for improved cargo restraint efficiency and safety.

Recent programs conducted by the Army have demonstrated that improvements in helicopter cargo restraint efficiency (reduced tiedown and release times) and safety are possible through the use of systems designed to absorb dynamic forces experienced during survivable crash conditions. However, efforts to date have been limited to incorporating energy absorption devices (load limiters) and flexible tiedown straps with existing aircraft floor fittings. A more effective cargo restraining system may be possible if energy absorption concepts are integrated with present helicopter structures or are incorporated in future helicopter designs.

Guidelines for an approved system have resulted from considerable work done by Aviation Safety Engineering and Research (AVSR) in establishing realistic threshold values of crash pulse envelopes from in-depth study of full-scale helicopter and fixed-wing crash tests. This was followed by the Crash Survival Design Guide covering all phases of crash survival (Reference 1).

To avoid a sterile approach to the present study, Boeing conducted an independent review of accident survivability and cargo handling operations in Vietnam.

A system is recommended which provides a significant improvement in crash survivability and is practical for field use. To achieve this design, the following tasks were undertaken and are included in this report:

- A review of cargo restraint technology
- The establishment of design criteria
- An analysis of the CH-47 helicopter structure
- Definition of candidate cargo restraint systems

- Restraint systems analysis and selection
- An evaluation of the selected system
- Preliminary design of the selected system

The following specialized information was compiled and is contained in the appendixes of the report:

- Description of internal cargo handling in Vietnam
- Design criteria for cargo restraint system safety
- Cargo tiedown time data
- Engineering survey comment on RVN operations

2. REVIEW OF CARGO RESTRAINT TECHNOLOGY

2.1 SECURING INTERNAL HELICOPTER CARGO LOADS

The support of field operations in combat situations places a premium on cargo tiedown and release time. There is a positive need for any simplification in current tiedown equipment and procedures that can be accompanied by increased crew safety in survivable crash situations.

Army programs have demonstrated the promising concept of improved helicopter cargo restraint efficiency (Reference 2) by reducing tiedown and release times through the use of energy absorbing tiedown features. The Reference 2 document also emphatically illustrates the need to evaluate current crash criteria (up to 8g forward static restraint) and the application of new criteria based on the dynamic response of the cargo to a crash pulse.

While the trend is toward the extended use of external sling loading for bulky, heavy items, many missions dictate the internal loading of mixed types of cargo as the most effective mode of transport. Internal cargo is limitless, in odd sizes, shapes and variety. Typical heterogeneous conditions which must be resolved from the standpoint of tiedowns are illustrated in Figures 3, 4, 5, 6, and 7. In most combat missions, however, the urgency of tactical operation limits the time available to load, restrain, release, and unload the multifarious objects carried. Effective use of the helicopter requires high productivity, particularly where the cargo handling becomes a significant portion of the short-stage missions flown.

The continuing hazard of tactical helicopter airlift must be weighed against the speed and efficiency of performing the basic mission. The mission comes first; as a result, many cargo tiedowns, if used at all, are of marginal and insignificant nature. These conditions, which were found to be typical and representative of field operations, are illustrated in Figures 8 and 9.

A study of cargo restraint problems and their resulting solutions would be absolutely useless unless these problems and solutions were studied in their actual environment. It is for this reason that tiedown requirements, cargo restraint training, and the application of both under operational conditions in Vietnam were investigated.

Figure 3. Evacuation of Vietnamese People and Their Belongings by CH-47 Helicopter.

Figure 4. Vietnamese Oxcart Being Manloaded Aboard CH-47A.

Figure 5. View of Cargo and Personnel Mix in CH-47 Aircraft.

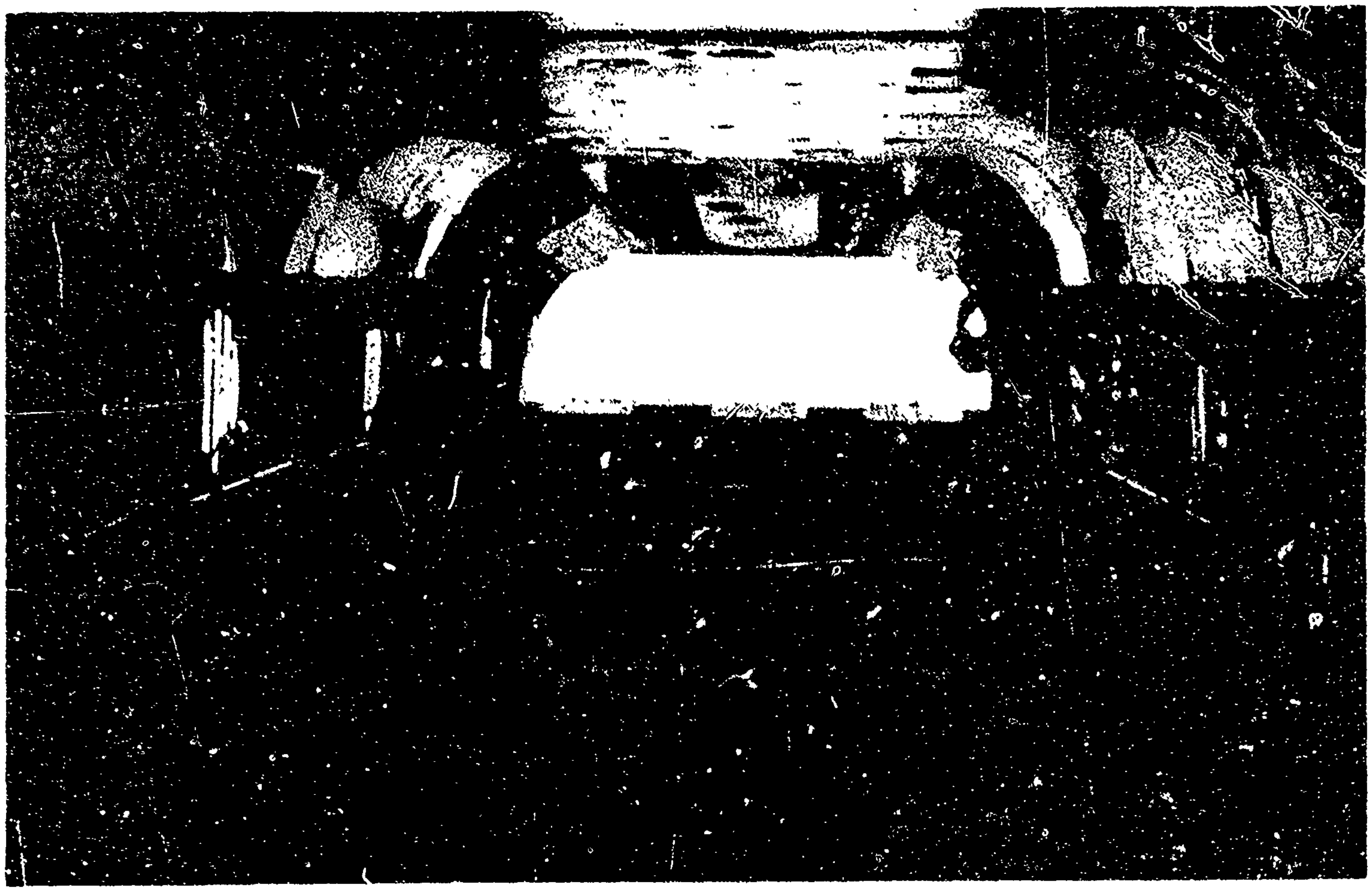


Figure 6. CH-47 Interior Showing Combination of Chains and Straps Used to Secure POL Sealdbins.

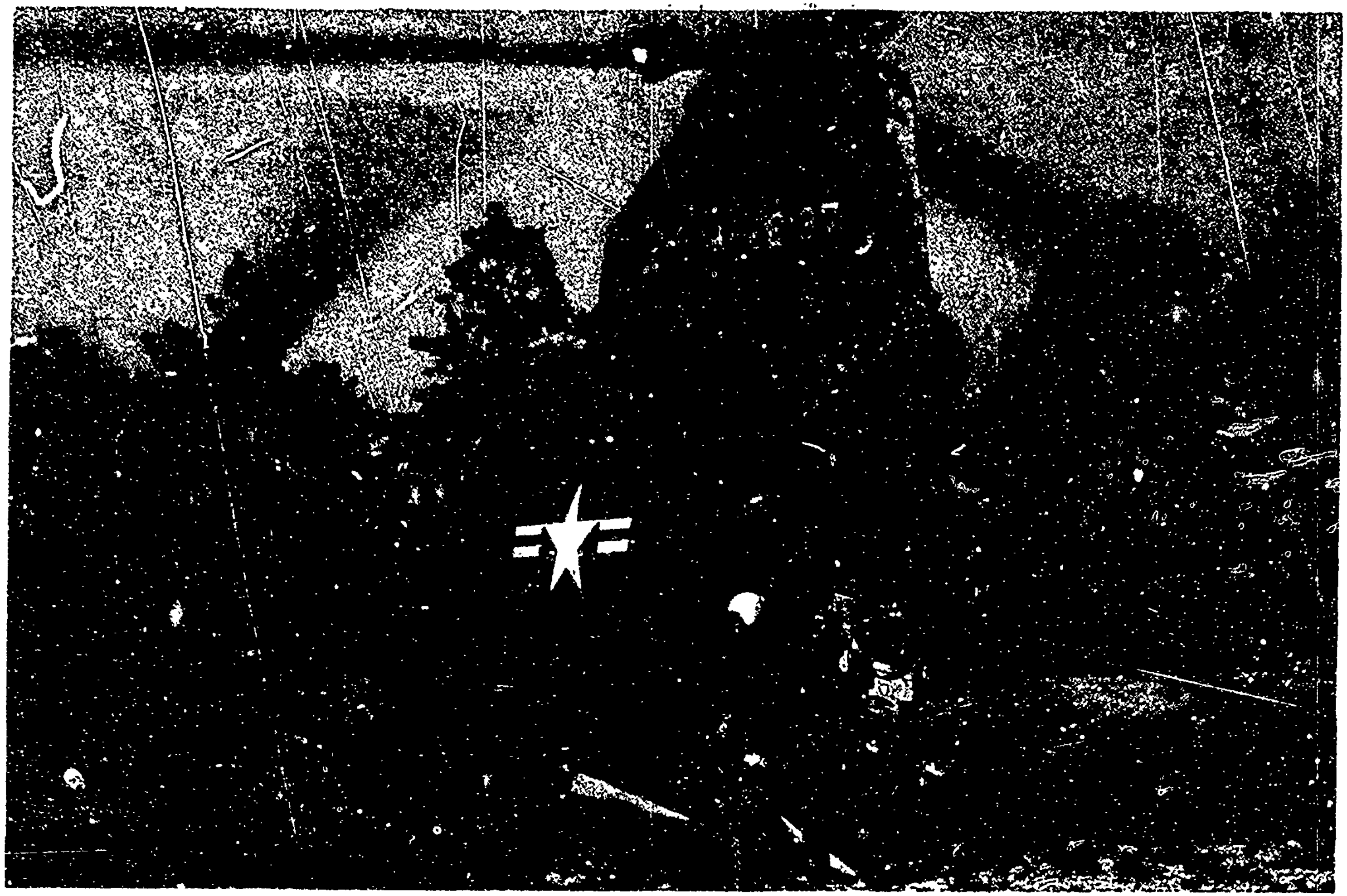


Figure 7. Self-Propelled Cargo Pallet (Mule) Delivering Miscellaneous Supplies in Vietnam.

Figure 8. Captured Vietcong Rice Being Loaded Aboard CH-47.

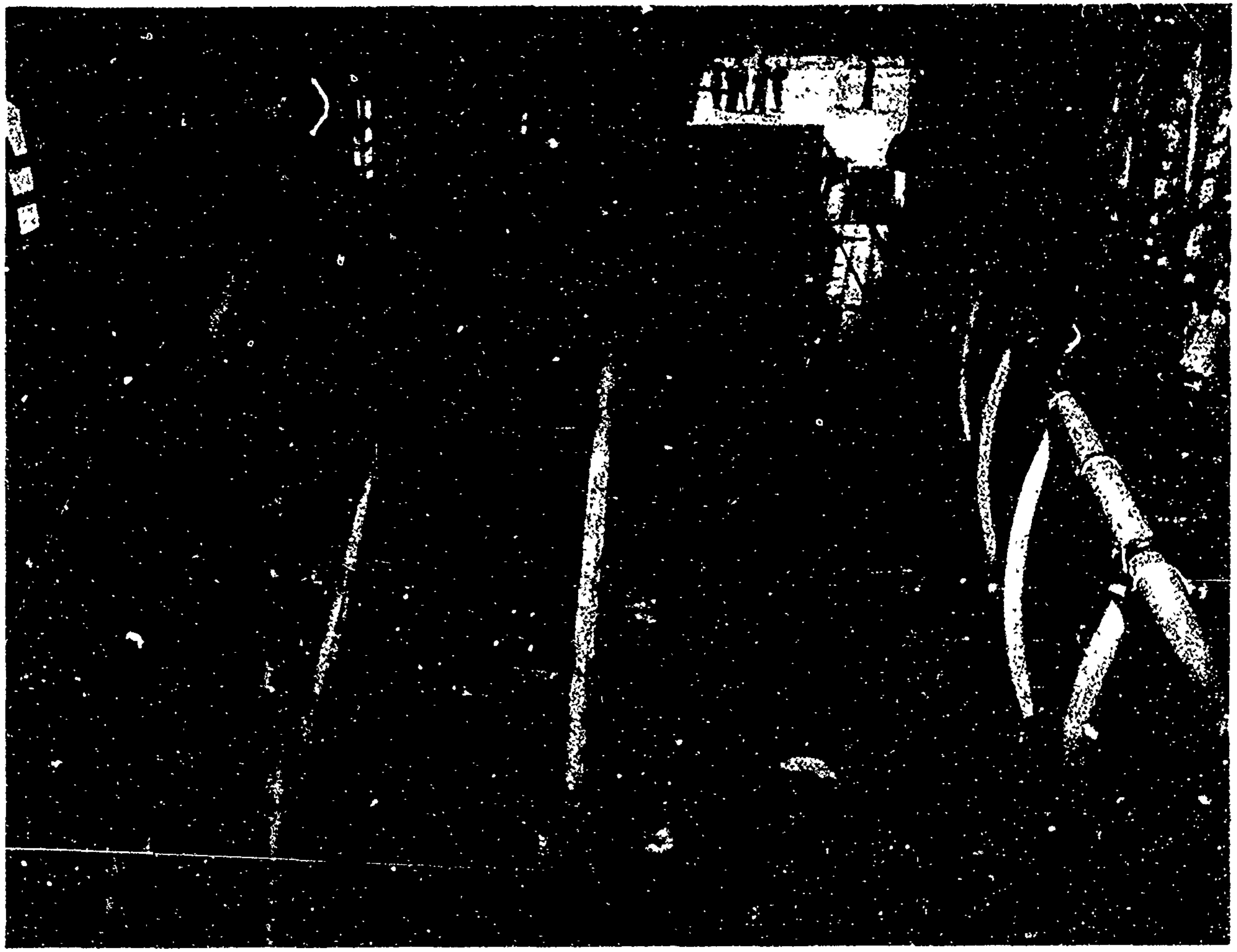


Figure 9. Typical Token Tiedown and Utilization of C-119 Roller Conveyors for Faster Cargo Loading.

Cargo Restraint Provisions

Cargo restraint provisions in present helicopters consist of a matrix of tiedown rings arranged for convenience as stipulated in the military specifications for the aircraft. These fittings are the points at which the variety of cargo carried is tied or restrained through the use of a strap, chain, or other device looped around vehicle axles or fastened to a similar fitting on the cargo. While these systems vary in detail for each individual aircraft, they are generally similar except for fitting locations and capacity provided. Table I lists the provisions normally aboard U.S. Army and Marine helicopters, as well as a Russian aircraft.

Guidance in the use of cargo restraining equipment is prepared for each individual aircraft. Typical of this information for pilot and crew is the CH-47 Flight Operators Manual, TM 55-1520-209-10 (Reference 3).

Static restraint criteria used today are shown in Table II. The g crash load factors for Navy aircraft are generally higher than those for Army aircraft, as a result of the special requirements for deck landings and related handling problems.

Recent Army programs have resulted in the formulation of dynamic crash criteria which relate dynamic impact g load factor to pulse duration. The pulse curve takes the form of an equilateral triangle, with the apex corresponding to the maximum g level. Average g levels published in the AVSER Crash Survival Design Guide are given in Table II.

Loadmaster Training

Loadmaster basic training is provided by the U.S. Army Transportation Center at Fort Eustis, Virginia, and is supplemented by work in field training units at such locations as Fort Sill and Fort Bragg.

Basic textbooks for this training are given in References 4, 5, and 6, which completely delineate the aircraft cargo provisions, cargo compartment volume and capacity, restraint criteria for specific aircraft, and procedures and equipment recommended for use.

The Army unit commanders are responsible for preparing supplies and equipment, and for loading, tiedown, and unloading of the aircraft. However, the aircraft commander has the responsibility for the approval of the final cargo tiedown configuration.

The referenced documents define in detail the handling and securing of typical loads to be encountered in the military service and the application of available straps, hooks, chains,

TABLE I. CARGO HANDLING AND RESTRAINT PROVISIONS

Item	Helicopter				
	CH-46D	CH-47C	CH-53A	CH-54A	MIL-10
Cabin, Pod, or Platform Sizes					
Length	24 ft 2 in.	30 ft 0 in.	30 ft 0 in.	31 ft 6 in.	28 ft 0 in.
Height	6 ft 0 in.	6 ft 6 in.	6 ft 6 in.	7 ft 9 in.	11 ft 6 in.
Width	6 ft 0 in.	7 ft 6 in.	6 ft 6 in.	7 ft 0 in.	-
Loading Profile	Rear Ramp Loading	Rear Ramp Loading	Rear Ramp Loading	Crane With Detachable Pod	Crane With Detachable Platform
Load Obstructions	None	None	Tail Boom	Tail Boom	None
Rollers					
Cabin	Yes	No*	Yes	-	-
Ramp	Yes	No*	Yes	-	-
Number of Tiedowns (and capacity)					
Cabin	30 (1.25K)	-	-	**	**
	14 (2K)	-	-	**	**
	31 (5K)	83 (5K)	49 (5K)	**	**
	-	8 (10K)	10 (10K)	**	**
	-	-	14 (20K)	**	**
Ramp	-	4 (5K)	6 (5K)	**	**
Quick Tiedown and Restraint System	No	No	No	-	-
Cargo Winch					
Load (lb)	2000	2-2000	3000	-	1760
Rate (fpm)	0 to 30	0 to 100	0 to 20	-	**

*Some user units have adapted C-119 roller conveyors. **Information not available.

TABLE II. G CRASH LOAD FACTOR CRITERIA

	Static Restraint G Load Factor							Dynamic Impact Avg G Load Factor (1)
Aircraft	All Military Helicopters		CH-47		CH-46		All Civil Helicopters	Army Rotary and Light Fixed-Wing Aircraft
Reference	AR705-35		TM 55-1520-209-10 Operator's Manual (2)		SD 544-1-6-3.4.7 (3)	NAVAIR 01-250-HMA-9 (4)	FAA FAR-29	Army Crash Survival Design Guide
Restraint Direction	Cargo	Cargo and Personnel	Cargo	Seats and Litter	Cargo	Cargo	Cargo	Cabin Area
Forward	2.0	4.0	4.0	8.0	8.0	10.0	4.0	13.5
Aft	2.0	2.0	2.0	-	-	7.5	-	13.5
Vertical	-	-	-	8.0	-	-	-	24.0
Up	2.0	2.0	2.0	-	-	3.0	1.5	-
Down	4.0	4.0	4.0	-	8.0	-	4.0	-
Lateral	1.5	1.5	1.5	4.0	3.0	3.0	2.0	8.0

Notes: (1) 95th Percentile of Survivability.
(2) Flight maneuver loads are 3g at 33,000 pounds gross weight.
(3) Basic crash loads.
(4) Proposed, unpublished.

and quick-release devices to the cargo retention problem. Also, great detail is given to proper cargo orientation and the number of tiedown devices to be used for each item. Considerable effort has been extended in providing short cuts for determining the proper restraint configuration. Many photographs are provided to show examples of proper usage and function of all the equipment. However, there is no explanation of how these rules and regulations may be applied under combat conditions. In this respect, the use of the instructions may be viewed as training objectives, with principal application expected in administrative and CONUS type air transport operations.

Vietnam Field Service Reports

In order to obtain a realistic appraisal of cargo restraint practice under operational field conditions, a review was conducted based on the experiences of Boeing field service representatives working with U.S. Army user groups in Vietnam. The range of activities reviewed included methods of securing internal cargo, equipment available in the field, flight safety practices relative to cargo handling, and crash survivability. Known survivable accidents or mishaps involving internal cargo (as either the primary or secondary cause of casualties) were reviewed with these field service representatives to learn where cargo handling practices were weak and could be improved, where they might be totally lacking, and what factors were related to fatalities.

The discussions with the field representatives pointed up several areas where improvements could be made. A detailed description of typical incidents cited is given in Appendix I, along with actual illustrations of potentially lethal cargo resulting from a combination of inadequate stowage conditions and poor tiedown practice. Conclusions about present cargo restraint systems, the environment in which they are expected to perform, and recommendations for improvement derived from these interviews are as follows:

General

Potential accident fatalities are reducible if proper cargo tiedown procedures are used. Since present restraint equipment is not being put to use because of time exigencies, poor operating habits result. Complete crash survivability may be unachievable because cargo restraint is basically contrary to the "mobility" concept provided by helicopters. Unless the proposed solution provides improvement of several orders of magnitude in time saved or simplicity, it will suffer from the same disuse experienced with present field equipment.

Safety Improvement

1. Need for flight safety awareness in cargo restraint is not apparent in the field. The Manual ST 55-161 (Reference 7) stresses protection of equipment against damage, not protection of personnel.

2. There is no apparent continuity of cargo restraint training provided for personnel in the field.

3. Ineffective cargo tiedown use appears to be the practice for combat and noncombat missions; the occasional exception is in the case of heavier vehicles.

Improved Restraint

1. Cannot be achieved by use of additional or new equipment, unless tiedown requirements are substantially decreased.

2. Increased restraint should be accomplished by using GFE and/or reducing the number of tiedown points required.

3. Build restraint means into aircraft.

Procedural Improvement

1. Recommend doctrine change to association of cargo restraint and flight safety of personnel.

2. Recommend training continuity in the field.

3. Use nets for flyaway equipment and Class A cargo tiedown.

4. Provide stowage for:

   a. On-board restraint equipment
   b. Field equipment (oil, tool boxes, personal gear)

5. Provide roller provisions and tailgate loading to speed movement of cargo in and out, thereby providing more time for cargo tiedown.

6. Feedback of information on internal cargo missions and equipment utilization is needed from the field to improve existing and future aircraft designs.

7. More complete accident reporting is needed concerning cargo tiedown security.

2.2 HELICOPTER CARGO RESTRAINT SYSTEMS

An integral helicopter cargo restraint system, if available today, could be used on a variety of aircraft. However, common problems would exist in its adaptation since current helicopter designs incorporating cargo-carrying provisions are based on static restraint design criteria. Typical cargo restraint and handling provisions now in use are summarized in Table I. Cargo floor plans for the CH-46, CH-47, and CH-53 helicopters are shown in Figures 10, 11, and 12, respectively. (Except for the newer CH-53, these aircraft designs are about 10 years old.)

Considerable need has been expressed from the field for quick-tiedown and -release equipment as an essential addition to each of these cabin-type, rear-loading aircraft. Typical of these expressions is a paper (Reference 8) by LTC W.R. Watson and LTC J.R. Dunham, Jr., U.S. Army, which states: "If cargo remains inside the cabin, a rapid, secure internal tiedown system should be developed."

Development work on quick-tiedown and -release equipment is being done by the Aeroquip Corporation at the request of the U.S. Naval Air Development Center, Johnsville, Pennsylvania. While the system devised is basically an assembly of available components, its initial trials have indicated a potential for rapid release of loads under critical landing and hostile environmental conditions (Reference 9). Photographs of the installations in a CH-46 aircraft are shown in Figures 13 and 14.

Rapid cargo handling is another basic requirement for the field (Reference 8); therefore, as recommended by the Douglas study (Reference 10), an automated system will be included as baseline equipment in this study of restraint systems. A feasible system has been devised for the CH-47 which meets these requirements when used with quick-tiedown and -release equipment. Schematically, the system will consist of the features shown in Figure 15.

2.3 ENERGY ABSORBING MATERIALS

A consideration of crash energy dissipation in aircraft design must be based on a knowledge of energy absorbing media. In general, an energy absorbing medium is one which can safely decelerate a moving body by "absorbing" the kinetic energy of impact through plastic flow or deformation while returning a minimum of energy to the decelerated object. The eventual choice of a material for use as an energy absorber in an aircraft structural application is important from the standpoints of weight, cost, and other characteristics. The objective of this survey is to identify a variety of materials which can be

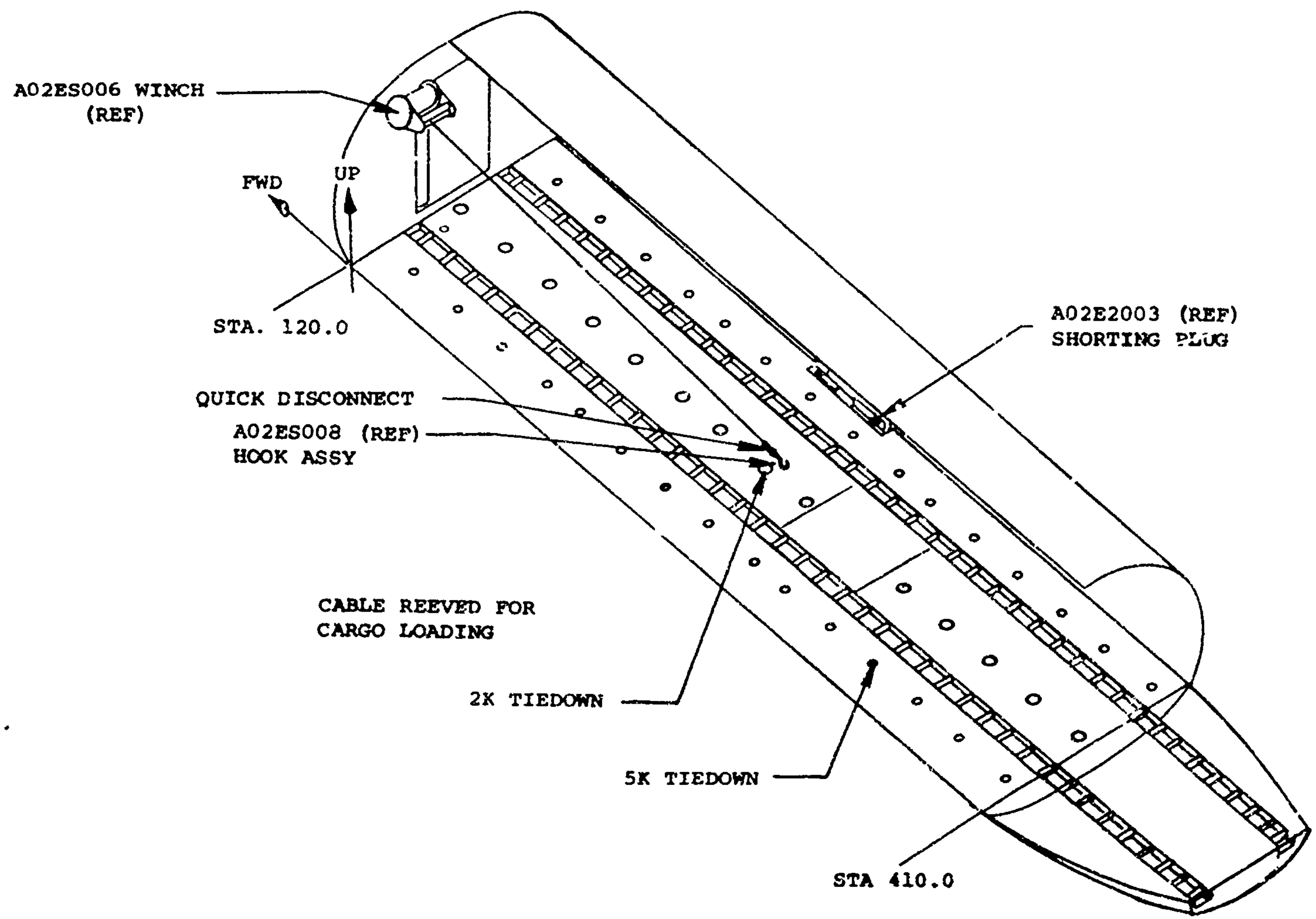


Figure 10. CH-46D Cargo Floor Plan.

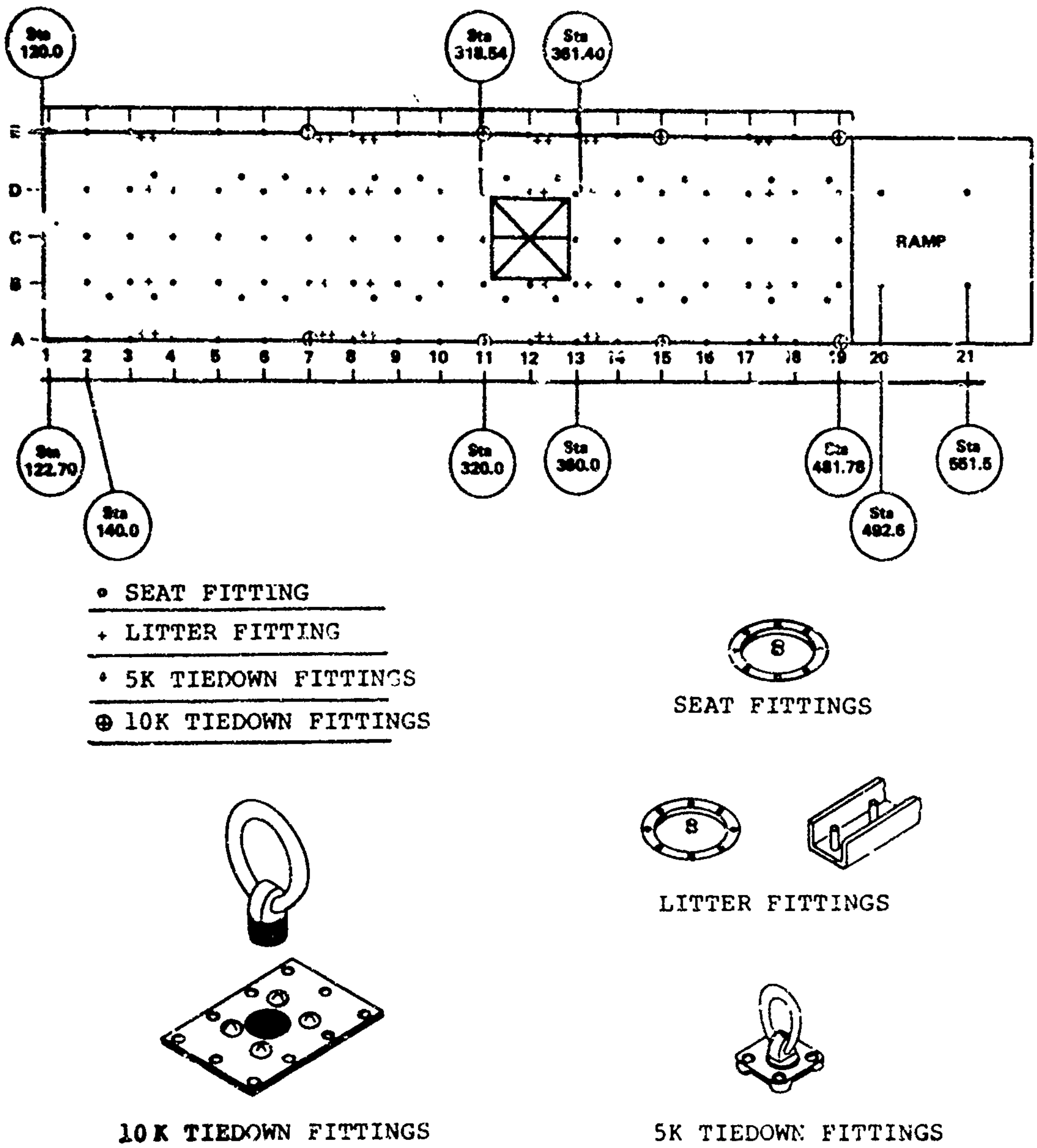


Figure 11. CH-47 Tiedown Fittings

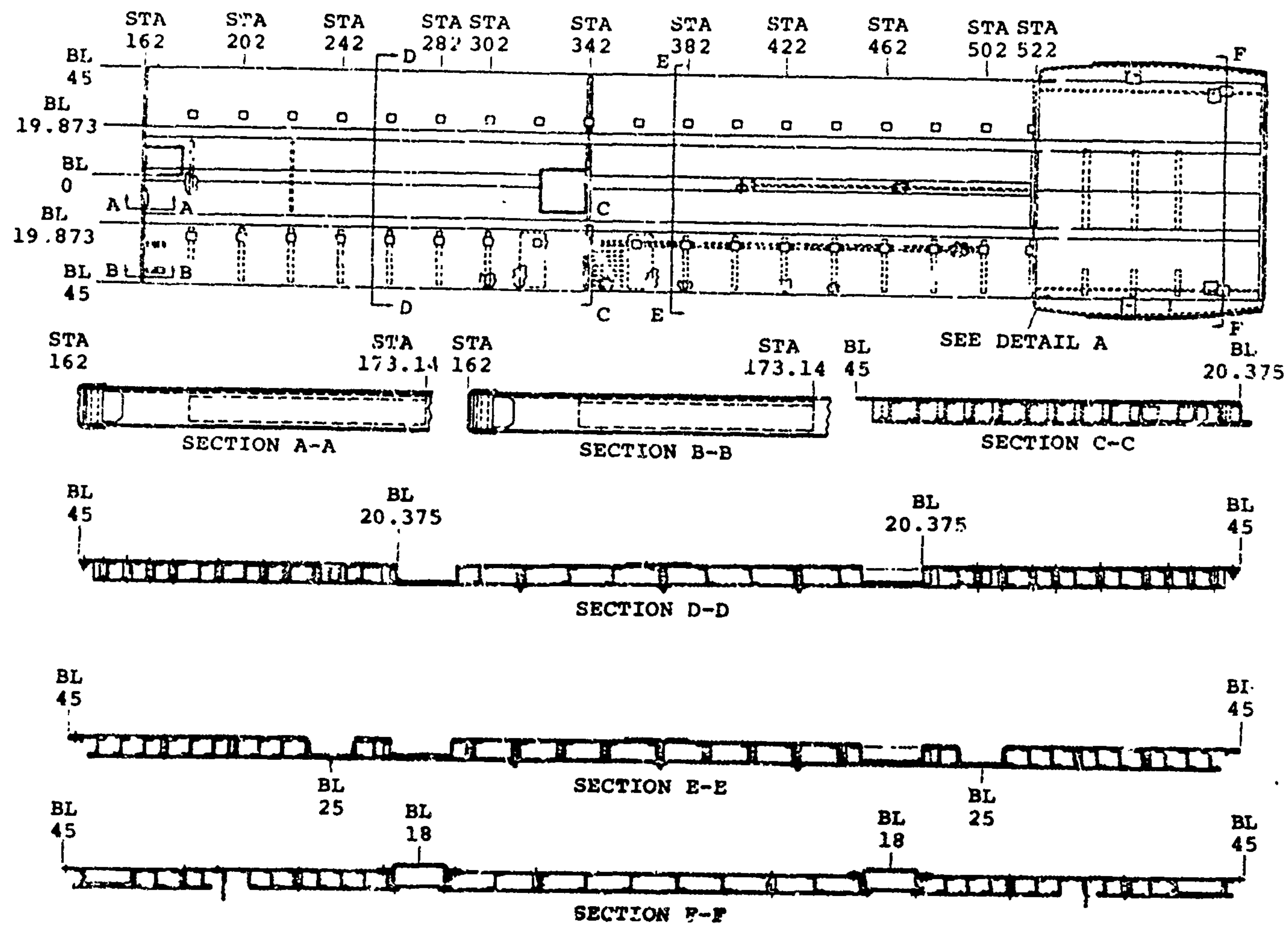


Figure 12. CH-53 Cargo Floor Plan.

Figure 13. Demonstration of CH-53 Overhead Net Quick-Tiedown and -Release System in Test Installation for Marines (Aeroquip).

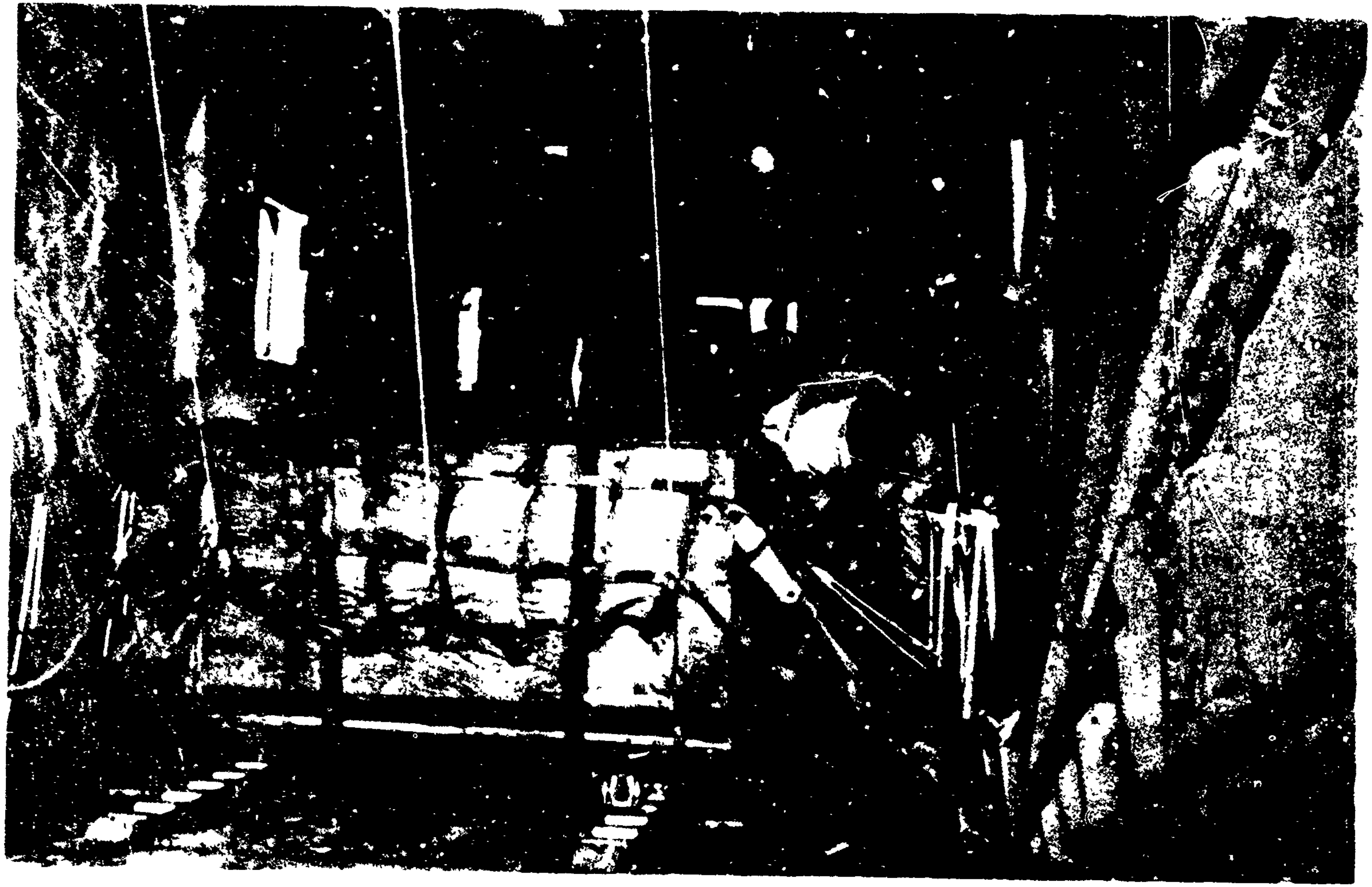
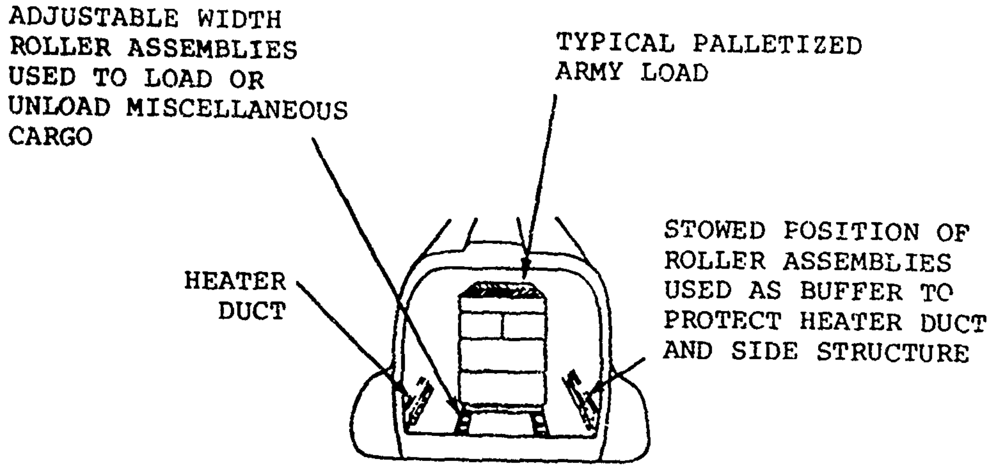
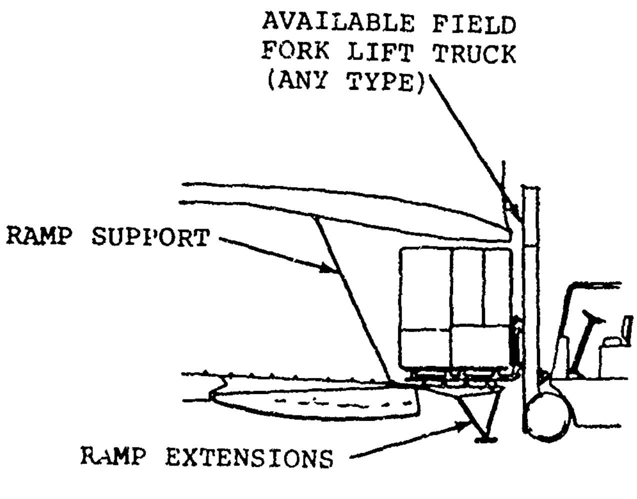


Figure 14. CH-53 Cargo Load Being Secured by Quick-Tiedown and -Release System in Test Installation for Marines (Aeroquip).



PORTABLE ROLLERS



"TAIL GATE" LOADING

Figure 15. CH-47 Rapid Cargo Loading System.

applied efficiently as load limiters. The scope of the review covered metals, nonmetals, and composites.

A limited survey was conducted through a review of the current literature and contacts with people active in the field. The industries covered included The Boeing Company, Seattle, Washington; the major automotive manufacturers in the U.S.; and load attenuator vendors or patent holders. While the survey cannot be considered comprehensive in depth or breadth, it did assist in establishing a reasonable knowledge of materials that could be applied to the energy absorption problem.

The use of materials for energy absorption is relatively new and undeveloped; therefore, these little used properties of materials are not as yet fully defined, and are not published with the more general characteristics. Unless an investigation of a specific material is undertaken, one can only make a review of percent elongation, reduction of area or impact strength (toughness), and then approximate the material's utilization as an energy absorber from basic stress strain curves.

In the automotive field, application of energy absorbing components (padded visors, padded dash, lap seat belts) has progressed from the design of separate shock absorbing gadgets to vehicle redesign in which principles of shock mitigation and energy absorption are applied to the auto body to prevent collapse and intrusion of the occupied space. Important examples of this are changes in the structural framework, body door design, and glass composition.

The following listings denote the manner in which materials may be used as energy absorbing media.

<u>Energy Absorption by Physical Deformation</u>

A. <u>Materials for Absorbing Energy by Crushing</u>

1. <u>Honeycomb</u>

   a. Aluminum
   b. Paper (Nomex): phenolic resin, impregnated
   c. Metals: stainless steel, titanium, molybdenum, tantalum, columbium
   d. Plastics: Fiber-reinforced plastic (FRP)

2. <u>Foams</u>

   a. Polyurethanes, density range of 1.5 to 60 pounds per cubic foot
   b. Metals

3. Fiber-Reinforced Plastics (FRP)

   a. Polyester laminates
   b. Epoxy laminates

4. Honeycomb and FRP

   a. Laminated honeycomb panels
   b. Elastomeric materials

B. Materials for Absorbing Energy by Extrusion

1. High viscosity (long time, low energy)

2. Low viscosity (short time, high energy)

   a. Silicones
   b. Freons
   c. Oils: mineral, petroleum, synthetic
   d. Water
   e. Gases

C. Materials for Absorbing Energy by Twisting, Bending, Shearing

1. Laminates

   a. Steel
   b. Elastomers

2. Solids

   Metals

Energy Absorbing Metals

A. Choice of Materials - Automotive and Aircraft

An industrial survey of information readily available on the energy absorption of metals has shown that even relatively common industrial alloys with well defined yield points (e.g., plain carbon steel) can be made to absorb large amounts of energy if properly designed. Because of their cost orientation outlook, the three major domestic automobile producers use this approach. Work in this field is done on a design oriented, minimum cost basis (References 11 through 16).

An alternate approach chosen by the aerospace industry to absorb energy for space flight was the use of specific material properties such as ductility or plasticity (in conjunction with design). This approach is materials

oriented and will sacrifice some cost for specific properties. In general, both approaches are equally valid if they adequately perform their intended functions.

B. Influence of Design

Specific designs that will perform effectively under impact conditions are honeycomb structures, frangible tubes, collapsible tubes, fluid-filled devices, solid thermoplastics, and various other load limiting configurations that absorb energy by severe plastic deformation of the individual constituents. It is important to note that most of these devices exhibit an axial displacement to axial force relationship, as represented in Figure 16 (from Reference 17).

The axial deflections for a particular load will vary with the choice of material used for the plastically deforming member. It is also possible to operate in various load levels using different strength-stiffness materials utilizing a single design as shown in Figure 17 (from References 17 and 18).

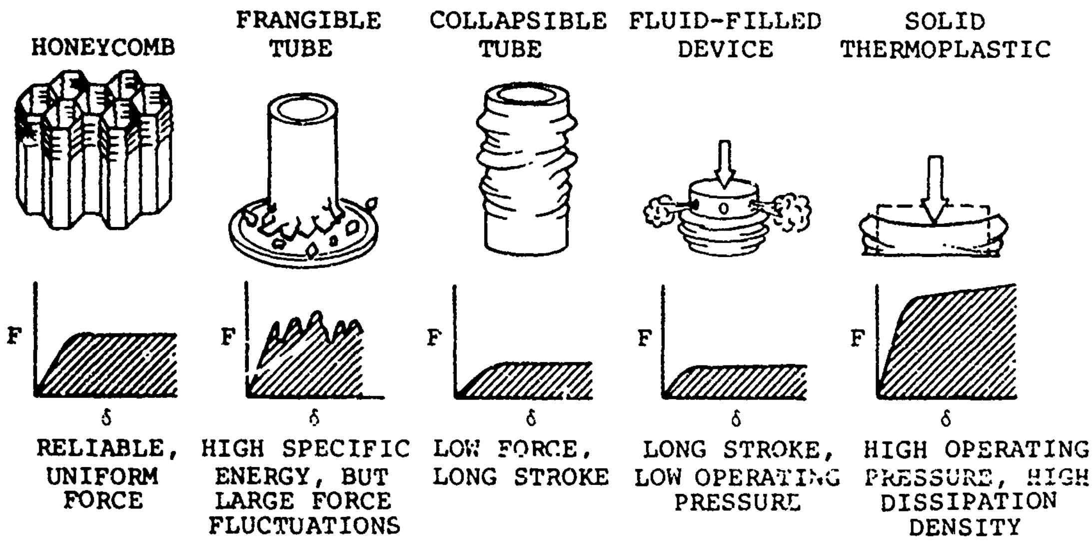
C. Influence of Use and Fabrication

The choice of materials for a particular design will be influenced by engineering parameters such as the following:

1. Strength to weight ratio
2. Corrosion resistance
3. Availability of material in various shapes and sizes
4. Cost
5. Machinability, formability, weldability

It should be noted that some of the above parameters are only indirectly related to the actual material, but, from a production standpoint, play a large part in the choice of the material.

A material's ability to absorb energy under impact conditions is based primarily on its ability to flow plastically without experiencing brittle fracture. As the material deforms or elongates, depending on the design of the load limiter, energy is being absorbed by the deformation process, and a resistance to loading is incurred. Materials with inherently few crystallographic slip systems would be poor choices in view of the large assortment of functioning designs. Additional or increasing resistance to loading is produced if a material with a high work hardening coefficient is chosen. Each additional increment of load will meet with greater resistance as strain hardening occurs. In general, a material's ability



(Reference 5)

Figure 16. Axial Displacement to Axial Force Relationship.

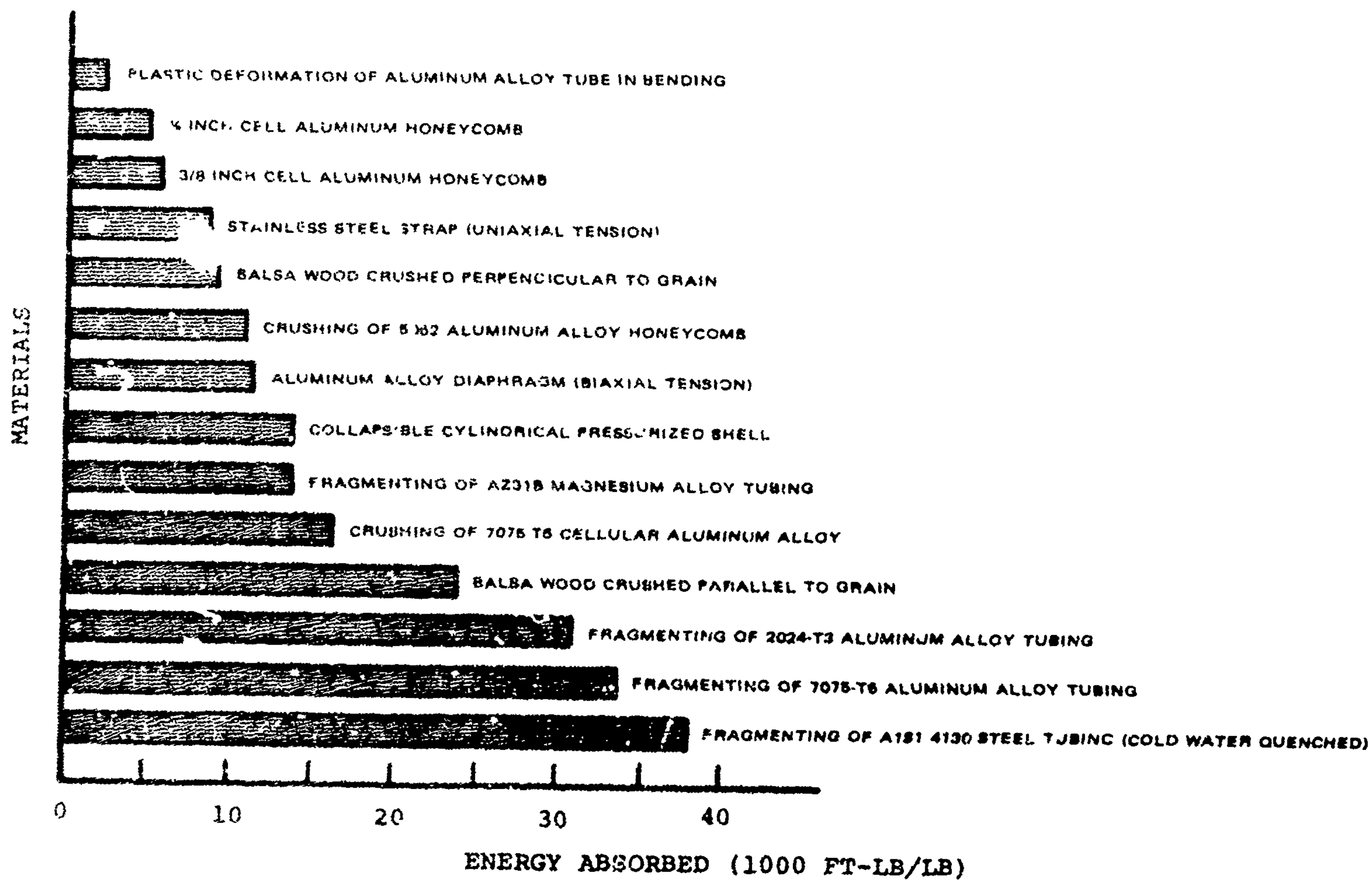


Figure 17. Comparison of Specific Energies of Frangible Tubes With Other Energy-Absorbing Devices.

to strain harden is a characteristic of secondary importance, whereas a material's ability to elongate under load is of prime importance. It can be specifically shown that large elongations in conjunction with high yield ultimate strength are indicative of a high energy absorption capability. This can be readily shown when considering a true stress-strain relationship (see Figure 18). The energy absorbed during plastic deformation or toughness (U_T) is represented by the area under the nonlinear portion of the curve or the integral

$$A = \int_{\varepsilon_1}^{\varepsilon_2} \sigma d\varepsilon \tag{1}$$

where ε = strain

σ = stress

(The elastic energy or area represented by the linear portion of the curve is not considered because it is energy recovered after the load is removed or after failure occurs.)

It is also apparent that the dimensional unit for this area is expressed by (psi x in.)/in. (stress multiplied by strain) or,

$$\frac{\text{lb-in.}}{\text{cu-in.}} = \frac{\text{Energy}}{\text{Unit Volume}} \tag{2}$$

By dividing this energy expression by the weight density of material, the expression then becomes

$$\frac{\text{Energy}}{\text{cu-in.}} \div \frac{\text{lb}}{\text{cu-in.}} = \frac{\text{Energy}}{\text{lb}} \tag{3}$$

or a meaningful engineering parameter. Since integration for a particular material is cumbersome, it can be approximated by the following relationship (Reference 19):

$$\frac{U_T}{\text{lb}} = \frac{\text{Energy}}{\text{lb}} = \frac{\left(\frac{\text{UTS} + \text{YS}}{2}\right) \times \text{Elong.}}{d} \tag{4}$$

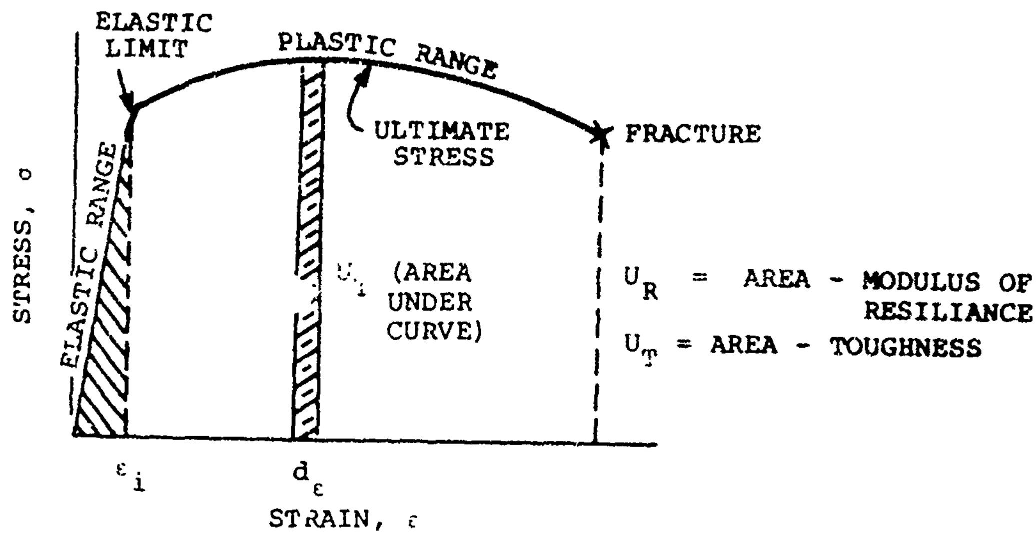


Figure 18. Typical Stress-Strain Diagram for a Ductile Material.

where UTS = ultimate tensile strength, psi

YS = yield strength, psi

Elong. = fractional elongation, in.

d = weight density, lb/cu-in.

The high values of energy per pound will be representative of high energy absorption. This is particularly useful because it requires the knowledge of only four easily obtainable material properties. Obviously, these properties are of paramount importance in choosing materials for load limiting applications. Table III presents a list of materials and their approximate computed energy absorption values.

The effect of the use of these materials in different energy absorbing devices may be seen by comparison with the values given in Table III. For example, R&D energy absorption investigations indicate that a wide range of efficiency (specific energy) is available: approximately 40,000 foot-pounds per pound for frangible tubes, about maximum for 4130 steel (Reference 17), and values of 400,000 to 800,000 foot-pounds per pound have been quoted for cyclic spring bending devices (Reference 20).

Energy Absorption by Nonmetals and Composites

The nonmetals and composites include honeycomb, isocyanate foams, styrene foams, metal foams, balsa wood, cardboard, foam glass, various padding and wadding, can and box-like structures, and elastomers.

A. Honeycomb and Foams

Honeycomb absorbs energy by crushing under load. The action of crushing develops a uniform level of stress. Honeycomb manufactured by both the corrugated and expanded method is widely used for general energy absorption application. Aluminum, reinforced plastics and paper are the most common materials. Energy absorption of the most commonly used honeycomb cores is limited to loading parallel to the longitudinal cell axis; if not, the average crushing stress declines rapidly. To overcome this, a special core is fabricated to provide a multidirectional energy absorption system. By the proper selection of cell size and foil thickness, honeycomb materials can have an average total energy capacity of 72,000 foot-pounds per cubic foot core. Honeycomb structures are now used throughout the

TABLE III. ENERGY ABSORPTION VALUES

	Material	Elongation (%)	Energy Absorption (in.-lb/lb)
1.	AISI 4340 Steel (177 ksi UTS)	15	90,500
2.	Custom 455 Maraging Steel (aged 1000°F)	16	117,000
3.	HY-150 Steel (150 ksi UTS)	18	98,300
4.	301 Stainless Steel (annealed)	50	114,000
5.	2014 Aluminum (T6)	13	83,800
6.	7075 Aluminum (T6)	11	85,000
7.	ZK60a Magnesium (T5)	11	81,000
8.	6Al-4V Titanium (aged)	10	93,000
9.	6-6-2 Titanium (aged)	8	87,000
10.	9-4-.20 Steel (220 ksi UTS)	17	120,500
11.	9-4-.45 Steel (Bainitic 270 ksi UTS)	13	114,000

helicopter for panels and load carrying structures. By redesign and proper orientation of the honeycomb core, the basic structure could be made to be a preliminary energy absorbing member.

Low density plastic foam materials are used in much the same way as honeycomb for energy absorptions. The deceleration strokes obtained with foams are usually up to only about 60 percent, although aluminum honeycombs are up to about 75 percent. The lower the percentage, the more materials are required to do a specific job. Plastic foams can be formulated with densities ranging from 1 pound per cubic foot to 60 pounds per cubic foot, as flexible or rigid as desired.

Current literature in the fields of shock and vibration indicates that new information will soon be available from widespread testing programs under way to establish the dynamic characteristics of foams and foamed metals.

B. Elastomers

Some types of elastomers have the ability to absorb energy and release it at a controllable rate and magnitude. As energy absorbers, elastomers can be used as bumpers, cushions, or mounts. An elastomer formulated to absorb and control energy can have "low transmissibility", that is, energy held in the material as heat and ultimately dissipated by conduction and convection. Low transmissibility is desirable in most cases. An elastomer can also have "high transmissibility", kinetic energy transmitted by the elastomer at a controlled rate to a reservoir or foundation. Energy absorption in an elastomer can be obtained by using an unreacted polymer having an inherently high damping factor and accentuating it by compounding or selecting a polymer with a moderate damping factor and compounding more elaborately. Some of the energy absorbing polymers that can be used are silicones, butyl neoprene, nitrile or urethane.

2.4 ENERGY ABSORPTION THROUGH PLASTIC DEFORMATION

Aircraft structures are designed to react loads that occur during flight, ground handling, and crash environments. Existing crash loads criteria used in aircraft design are predicated upon static load factors geared toward strengthening pertinent structural components. The static crash load criteria are applicable to restraint of seats, personnel, and cargo, as well as engine mounts and other structural elements.

Pilots in U.S. Army aircraft currently use a restraint harness enveloping their shoulders and waist. In addition, specification MIL-R-8236 requires installation of an inertia reel on the crew seats which acts as an automatic locking device to provide full freedom of movement during normal operation and complete restraint during sudden decelerations. Internal restraint of personnel on litters is accomplished by encircling the stretcher with several pieces of webbing. The shoulder-waist harness mentioned above would be appropriate for longitudinal restraint. However, present vertical litter restraint designs offer limited protection for downward crashes.

Aircraft seats are rigidly attached to the airframe through floor structure and have inherent plastic deformation characteristics that respond to imposed loads. However, material characteristics distinctly limit the system's resistance to impulsive loading.

The type of restraint for cargo varies with the type of package transported. Cargo carried in U.S. Army aircraft is both homogeneous (vehicle, aircraft engines, etc.) and mixed (food packages, medical supplies, etc.) in nature. Bulk or mixed cargo is either prepalletized prior to loading or placed on the aircraft floor for net-type restraints. Tiedown of homogeneous cargo is usually accomplished by chains or web-type restraint devices. Such restraint methods are typical of the air delivery mode of transportation.

For airdrop operations, prepalletized cargo is placed on rollers attached to the aircraft floor and is restrained by web devices with a cutting mechanism for quick release. Instances occur when web and chain tiedown devices are mixed for restraint in a defined direction, which results in degradation of the restraint system because of the different elasticity characteristics. It has been further ascertained from field observers that little restraint, if any, is used during helicopter combat operations, and nets are seldom carried with the aircraft.

Studies associated with aircraft response to dynamic impact loading have shown that occupant survivability and protection can be improved if occupant restraint, cargo restraint, and hazardous environmental conditions are considered in initial design. In recent years, studies have been inaugurated to determine and develop design criteria and design concepts to cover all aspects of aircraft safety and survivability.

A statistical study of crashes involving U.S. Army aircraft (since 1960) was undertaken to establish the range of impact conditions related to survivability. The human tolerance to withstand abrupt accelerations and the parameters associated

with impact pulse imparted to the aircraft were the major areas of investigation. The factors affecting human tolerance include magnitude, duration, rate of onset, and direction of applied force felt by the occupant. A typical survivable crash pulse imparted to aircraft, when relating aircraft deceleration to duration, takes the approximate shape of an equilateral triangle. In general, large fixed-wing aircraft realize higher impact pulses during crash events as opposed to rotary-wing or light fixed-wing aircraft. Longitudinal impact energy is dissipated in compression and acceleration of the soil median and friction between impact surfaces, with a small percentage absorbed by structural deformation. For vertical impacts, a somewhat higher percentage of energy is absorbed by the fuselage structure. However, most of the impulsive forces are transmitted to the cargo and crew.

A study by All American Engineering Company (AAE)(Reference 21) pertinent to dynamic restraint requirements defines the deficiencies of the existing U.S. Army restraint techniques. The report delineates a dynamic analysis, relating crash pulse criteria to restraint system deflection, and formulates an applicable load-limiting wire-bending energy absorber concept.

The pertinent problem areas associated with cargo restraint in the Reference 21 study were: available floor tiedown fittings after cargo is placed in the aircraft compartment, cargo tiedown and release time, the number of tiedown straps required to correctly restrain cargo, and the need for dynamic criteria in place of existing static requirements.

The Reference 21 report shows a dynamic analysis of cargo deflection as a function of elastic restraint characteristics, constant cargo g load, aircraft deceleration, and time parameters. The report also suggests that the wire-bending energy absorber, combined in series with a low-elastic web tiedown restraint (preferably Dacron), offers maximum restraint energy when evaluated against the factors of operational feasibility, payload capabilities, weight, cost, and technical feasibility.

The feasibility of the low-elastic strap in conjunction with wire-bending energy absorbers as a cargo restraint system was proven during a helicopter crash testing program (Reference 2). This was accomplished by restraining two separate test loads to a common g load factor. One package was restrained by the new tiedown system and the other package by the existing U.S. Army nylon straps. The new system remained intact while the nylon restraints failed immediately after impact. The tests paved the way for evaluation of experimental hardware. Design verification was obtained by dynamic testing a number of these units on a laboratory test rig.

The dynamic and helicopter crash tests were so definitive that 5,000- and 10,000-pound absorbing Dacron strap units have been manufactured and sent to Vietnam for evaluation.

One objective of this study is to integrate energy absorption philosophy and helicopter structures in order to improve system effectiveness beyond the gains realized by the load limiting device alone. Use of the basic aircraft structure as the energy absorption medium would require analytical techniques pertinent to plastic deformation of materials. The analysis could consider either time-independent or time-dependent behavior of materials.

Selection of the method would be based on the physical properties of the structural material, accuracy of analysis, time rate of application, and removal of loading of the structure. In specific cases with relatively simple systems such as load limiters, a time-independent analysis would be used. In more complex and highly redundant structures, such as aircraft, where weight and accuracy are of vital importance, a time-dependent analysis would be more suitable. For these applications, computer analyses (as reported by Boeing and Douglas in References 22, 23, 24, and 25) have been used.

The following discussion is an excerpt from "Introduction to Mechanics of Deformable Solids" (Reference 26), which is an introduction to plastic analysis of deformable solids. The context will briefly describe time-independent and time-dependent behavior of materials. In simple form, derivation of a beam in pure bending for time-dependent behavior of materials is presented.

Time-Independent Behavior of Materials

Time-independence to the behavior of materials is best illustrated by considering a tension member with the load-deflection curve depicted in Figure 19. Loading the member to the P_Y value will result in linear-elastic behavior of the material. By increasing the load further, the material becomes plastic and the change in load to deflection ($dP/d\delta$) decreases until fracture occurs. The area under the curve represents the work done by the particular material which is partly stored as elastic strain energy and partly dissipated in plastic deformation. The stored energy is recoverable when the load is removed. The recovery essentially follows the straight line portion of the curve as delineated in the figure. However, a permanent set results with the tension member becoming longer and thinner. Virtually no change in volume occurs. Reloading the member results in essentially the same curve shape as if unloading had not taken place. The loop formed (see Figure 19) by the unloading and reloading is called a hysteresis loop.

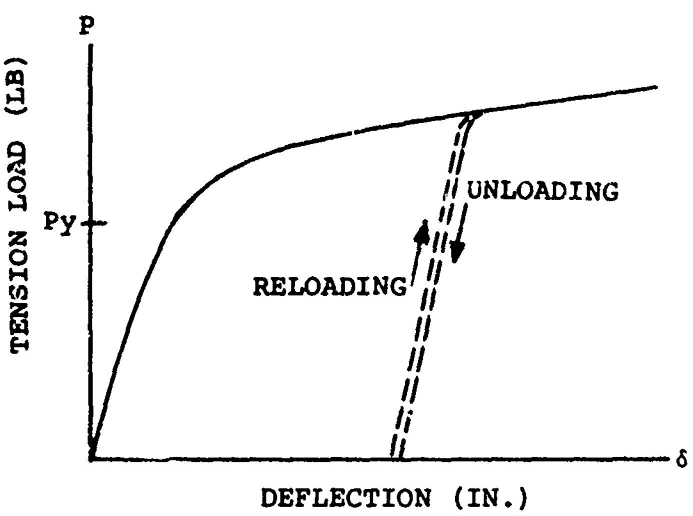


Figure 19. Load-Deflection Curve for Tension Member.

Time-Dependent Behavior of Materials

In general, for high rates of loading at or above room temperature, behavior of materials becomes time-dependent. The effect of time is primarily associated with creep and relaxation behaviors. Creep is the time-dependent deformation produced in solids subjected to stress and relaxation, and is defined as the time-dependent decrease in stress at a given deformation. Two basic idealizations of time-dependent material behavior are the linear-viscous and linear-viscoelastic.

A linear-viscous material is analogous to a linear spring where change in length represents material strain and force represents stress. The material will exhibit no recovery and responds to a given stress at any time in the same manner as at any other time. Considering the homogeneous tension member again, the rate of strain $d\varepsilon/dt$ is proportional to tensile stress σ given by the equation

$$\frac{d\varepsilon}{dt} = \frac{\sigma}{C} \tag{5}$$

where C = a constant of the material.
Also,

$$\frac{d\delta}{dt} = \frac{PL}{AC} \tag{6}$$

where $\frac{d\delta}{dt}$ = rate of deflection

L = length of tension member

A = area of tension member

It is to be noted that Equation (5) is the analog of the theoretical elastic elongation equation $\delta = PL/AE$, where E is the modulus of elasticity.

The higher the viscosity or the higher the value of C, the slower the application of load. Also, relaxation is instantaneous at constant strain, where $d\varepsilon/dt$ is zero, resulting in P and σ being zero. It is not possible to realize a sudden finite change in ε without having a finite change in time, as this would require an infinite σ. However, a finite change in ε can result with a finite change in time by a sufficiently large σ.

A linear-viscoelastic material, which combines elastic and viscous response, is closer to actual time-dependent structural material than the purely viscous material. A viscoelastic model known as the Maxwell model is shown in

Figure 20. The model delineates the viscous element pictorially by a dashpot and assumes the spring or linear element in series with the dashpot. For the linear portion of the model,

$$\varepsilon^{e} = \frac{\sigma}{E} \tag{7}$$

where ε^{e} = the strain in the linear range.

Also, from equation (5)

$$\frac{d\varepsilon^{v}}{dt} = \frac{\sigma}{c} \tag{8}$$

where $d\varepsilon^{v}/dt$ represents the rate of strain for the viscous element. Differentiating Equation (7) and adding to Equation (8), the differential equation for total rate of strain is

$$\frac{d\varepsilon}{dt} = \frac{1}{E}\frac{d\sigma}{dt} + \frac{\sigma}{E} \tag{9}$$

To understand the conceptual or practical usefulness of this equation and the model it represents, an analysis of its behavior in creep and relaxation is necessary. (This analysis is discussed in great detail in Reference 26.)

Beam in Pure Bending

The application of time-dependent behavior of materials to beams in pure bending is presented for the linear-viscous idealization.

In pure bending, each cross section (dx apart) of the beam is subjected to the same bending moment (see Figure 21). Therefore, each length dx will behave in the same way, and the same change in rotatation $d\theta$ between the two bounding cross sections can be expected. As depicted in the figure, all lines or fibers parallel to the neutral axis of the beam must become concentric circular arcs, where those fibers at the top of the beam shorten and those at the bottom lengthen. The strain relationship is:

$$\varepsilon = \frac{Y\theta}{L} \tag{10}$$

but

$$\frac{1}{e} = \frac{\theta}{L} = K \tag{11}$$

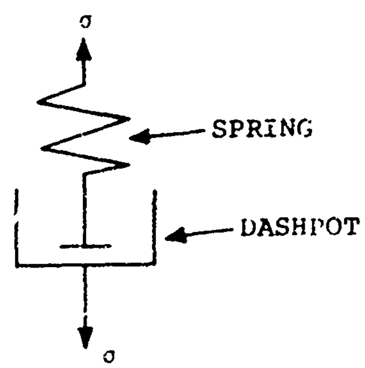


Figure 20. Maxwell Model of Linear-Viscoelastic Material

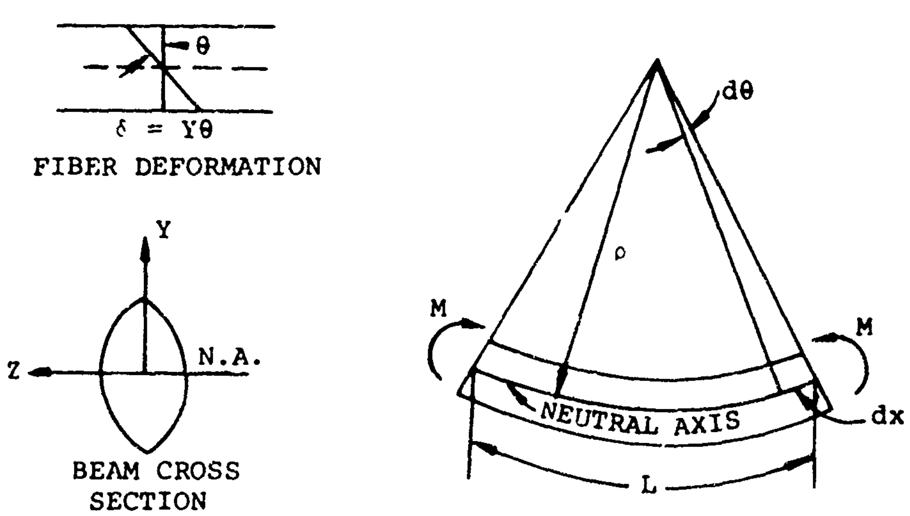


Figure 21. Beam in Pure Bending.

therefore,

$$\frac{d\varepsilon}{dt} = y \frac{dk}{dt} \tag{12}$$

Using δ = Mc/I and Equations (5) and (12), then

$$\frac{dk^v}{dt} = \frac{M}{CI} \tag{13}$$

Figure 22 is delineated to show the development of the plastic moment M_O for a homogeneous rectangular beam. First, there is an elastic response in which the distribution of stress is linear with distance from the neutral axis located at the mid-height of the beam. This stage terminates when the maximum, or extreme, fiber stress reaches σ_O simultaneously at the top and the bottom of the beam. The moment for this first yield is denoted by M_y. As the moment is increased beyond M_y, the response is partly elastic and partly plastic. The bending stress σ cannot exceed σ_O, the strain still is proportional to the curvature k, and the stress distribution on the cross section is simply the stress-strain diagram turned 90 degrees from its usual position. The slope of the moment-curvature curve decreases continuously as M rises asymptotically to M_O. Actually, the difference between M and M_O becomes very small, even for the rectangular cross section, at a rather small multiple of the limit of fully elastic curvature k_y.

2.5 ENERGY ABSORBING DEVICES

To quote the introductory statements of a recent article on load attenuation, "Any physical characteristic that is predictable can usually be adapted to engineering advantage... Failure itself, generally thought of as 'bad', can be a useful mechanism because many failure modes and characteristics are predictable" (Reference 17).

The following text describes various concepts developed and/or being tested for load attenuation use. Where possible, available performance curves are shown to indicate response characteristics and energy absorbing capacities. Possible applications to an integral helicopter cargo restraint system are also shown. Table IV is presented to show the efficiencies of load limiting devices reviewed.

All of the devices shown appear to be feasible in concept for the contract application. Some devices (the AAE, VZA, ARDE, and Boeing configurations) could be developed on a short-term production basis; other designs (MRI and Menasco) tend to fall in the long-term development period.

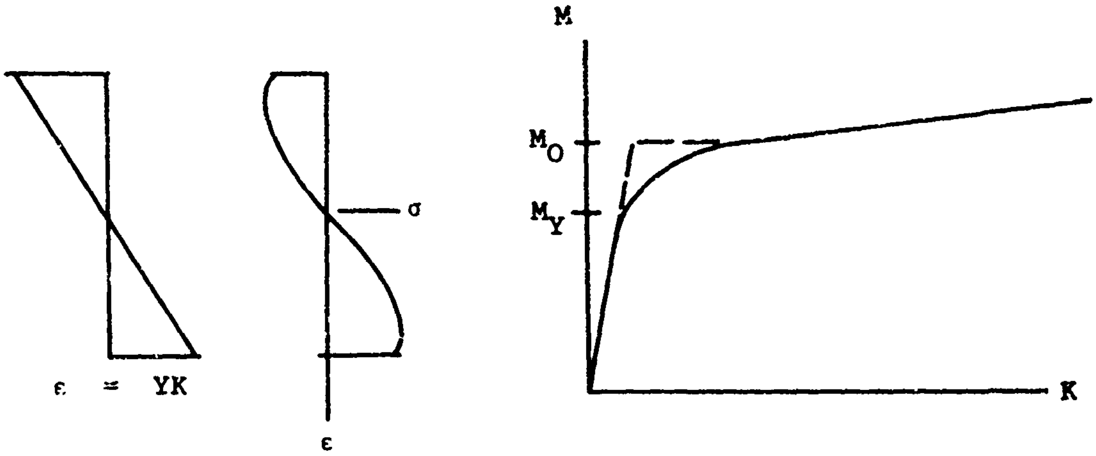


Figure 22. Idealization of M Versus K.

TABLE IV. EFFICIENCIES OF LOAD ATTENUATION DEVICES REVIEWED				
Manufacturer and Model	Design Load Capacity (1000 lb)	Design Stroke (in.)	Weight (lb)	Efficiency (ft-lb/lb)
<u>AAE</u>				
Type I	5.0	6.0	4.0	625
Type II	10.0	6.0	5.5	920
<u>VZA</u>				
LL-3	2.5	4.0	0.34	2,450
LL-4	0.75	12.0	0.10	7,500
LL-5**	5.25	3.0	1.60	821
LL-6	1.0	12.0	0.23	4,350
LL-7	4.0	24.0	1.60	5,000
LL-8	2.4	36.0	*	*
LL-Compression	2.0	8.0	0.34	3,920
LL-9	0.65	72.0	0.6	6,500
LL-10	2.4	43.0	*	*
LL-11	5.0	24.0	1.75	5,704
LL-12	11.0 for 48 in.***	120.0	*	*
LL-14	4.5 to 5.0	12.0	1.4	3,575
LL-15	9.0 to 10.0	12.0	2.7	3,710
<u>MRI**</u>	5.0	6.0	1.25	2,000
<u>ARDE</u>				
(a)**	5.0	6.0	4.4	569
(b)**	23.0	6.0	4.4	2,613
(c)**	5.0	6.0	1.44	1,738
<u>Boeing</u>				
SK18595	5.7	5.0	2.2	1,080
143E5003-1	3100	9.0	1.7	1,370
Menasco				
Solid Medium	8.0	6.0	10.0	400

* No data available at this time.
** Capable of stroking in either direction.
*** Decreases from 11,000 to 0 lb from 48 to 120 inches of stroke.

Stroking Split Tube

This concept, designed for shipboard application, has been undergoing test evaluation by the Aeroquip Corporation of Jackson, Michigan, for the past year. Recent conversations with the manufacturing personnel indicate they have been discouraged by the inconsistent breakaway or initial peak forces experienced to date and have turned toward other concepts. No test data, cost, size or weight, is available at this time. As indicated by Figure 23, the design consists of an inner slotted tube and an outer tube with a reduced opening at one end. Upon loading the device to a preselected level, the shear pin fails and the slotted tube is pulled through the reduced end of the outer sleeve.

Metal Bending Devices

There are several types of metal bending devices: wire, tube, strap, bar, ring and tape. Most of these concepts are in the development stage.

Figure 24 illustrates a wire-bending concept developed by All American Engineering under contract to USAAVLABS. These 5K and 10K capacity load attenuators have been tested and sent to Vietnam for field tests; to date, no data has been available from the field. The design has been documented in References 27, 2, and 21. Table V shows a tabulation of these load limiter characteristics, and Figure 25 illustrates the performance curves based on actual tests.

The equipment produced was unduly expensive, and the vendor recommends (Reference 27) that a brief but intensive program be carried out to reduce the unit cost. The study should include:

1. Improved tooling
2. Use of new material

AAE estimates a production cost for the Type I and II units less straps in the order of \$80/unit and \$96/unit for quantities of 2,000. These units are used as the baseline equipment for the system trade-off study in Section 7.

The curves of Figure 25 depict a drop in load level, apparently as a result of a decrease in back tension on the guides. The back tension is caused by the pressure of the wire against the guides, which results in friction buildup. The required stroke for a constant load intensity can be accomplished by allowing the required wire free end to extend beyond the wrapping of the guide. However, for compactness, it may prove more feasible to wrap the wires a number of revolutions around the guides and allow a small drop in load for each revolution unwrapped (see Figure 26).

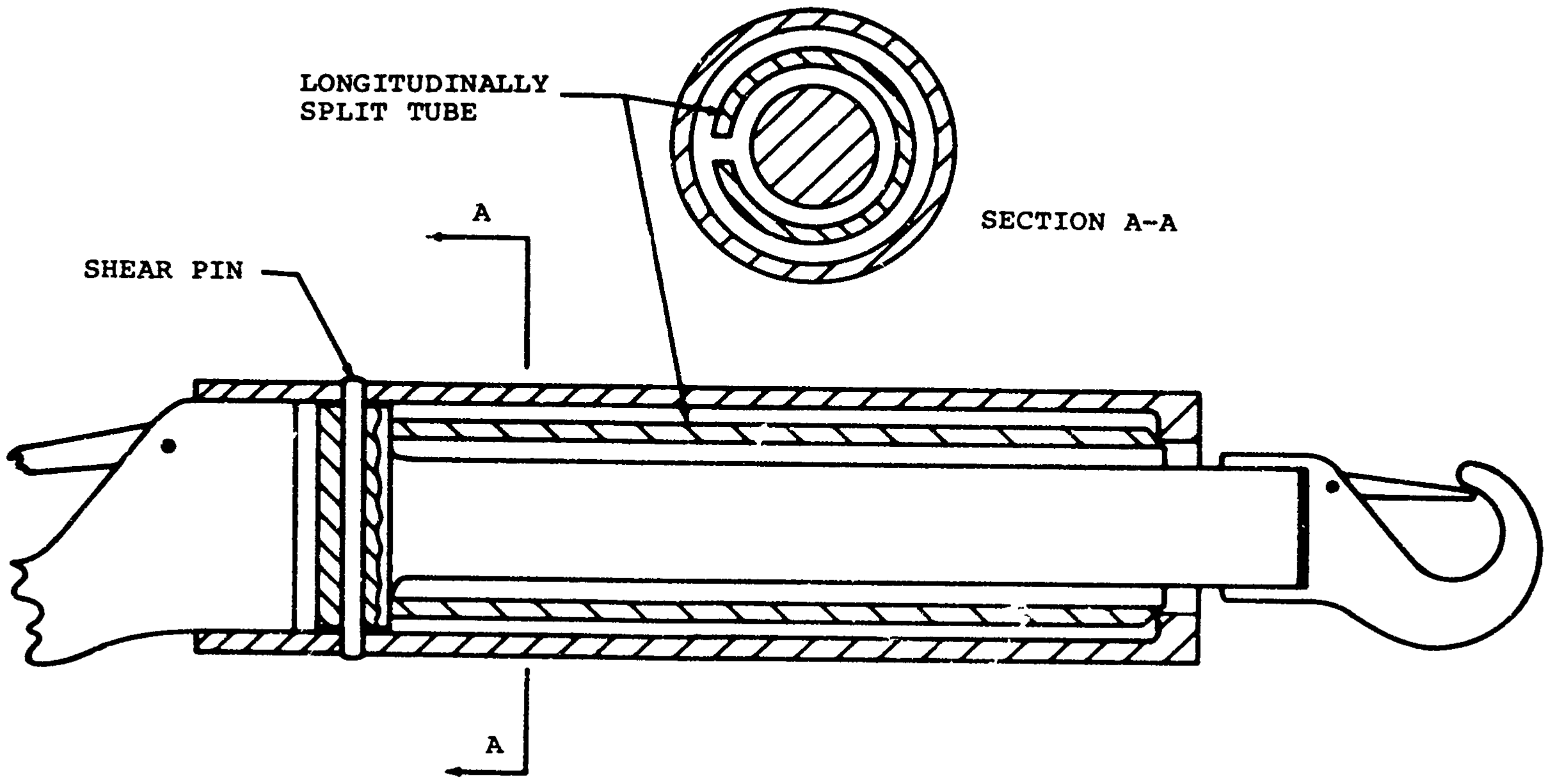


Figure 23. Proposed Load Absorber Using Split-Tube Principle (Aeroquip).

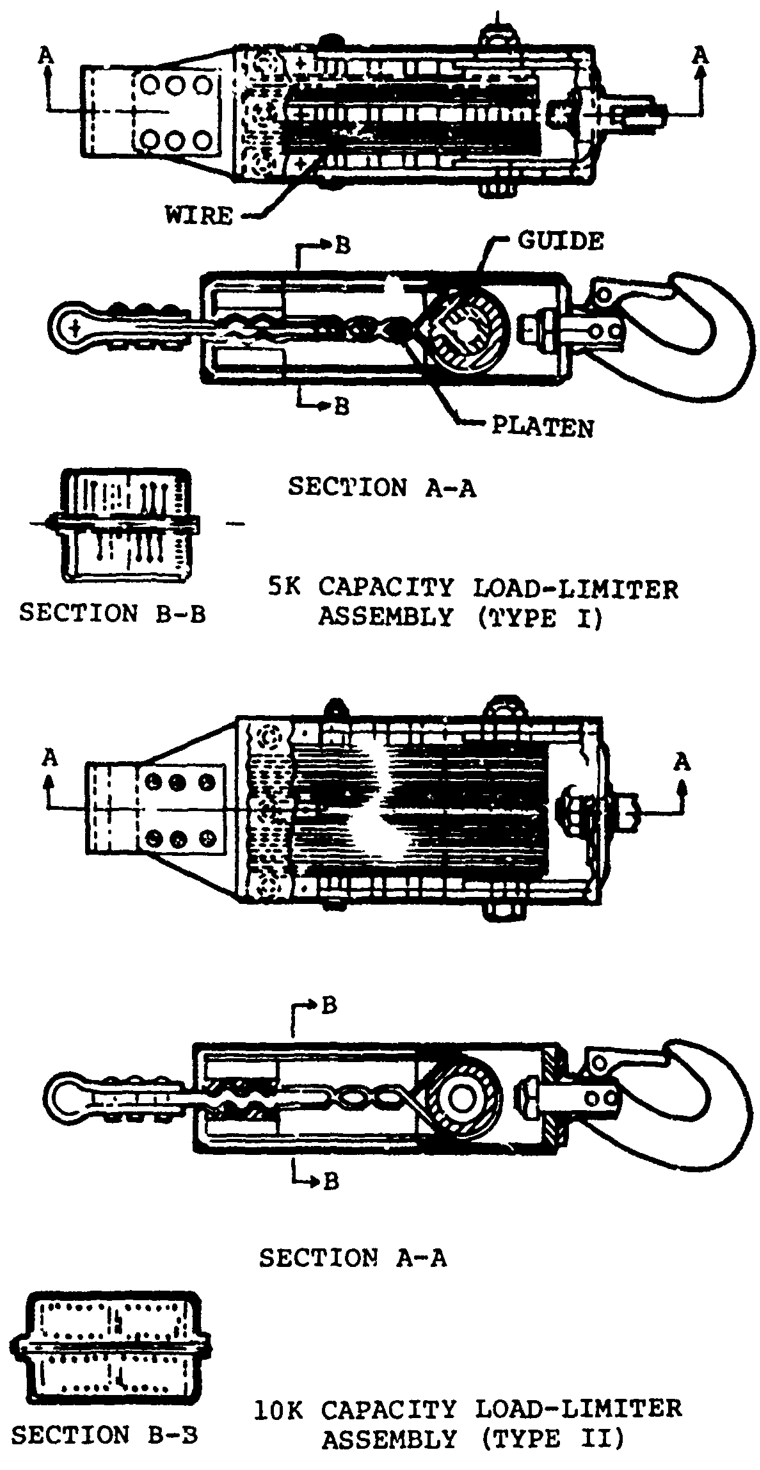


Figure 24. Wire-Bending Principle (AAE).

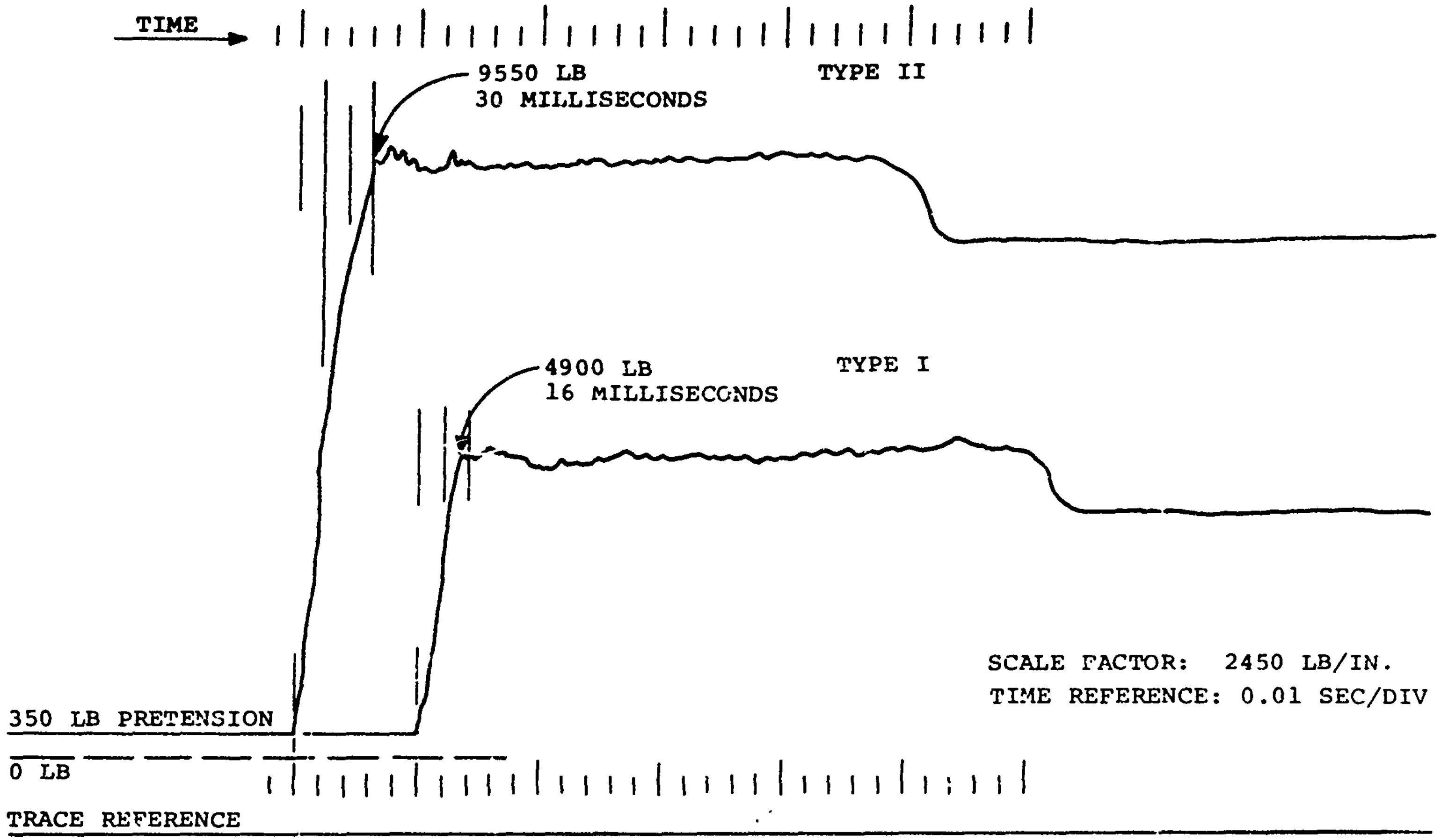


Figure 25. Typical Dynamic Test Curves for Type I and Type II Load Limiters (AAE).

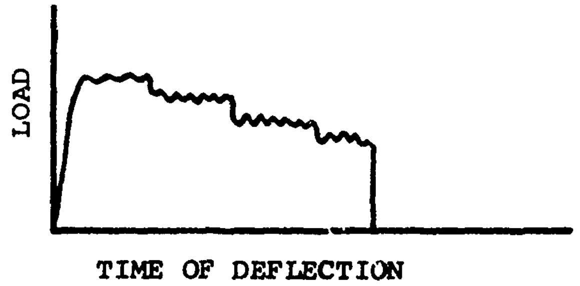


Figure 26. Load Versus Time of Deflection.

TABLE V. AAE LOAD LIMITER CHARACTERISTICS		
Characteristics	Type I	Type II
Rating (lb)	5,000	10,000
Nominal Yield Point (lb)	4,500	9,000
Yield Range (lb)	3,825 to 4,950	7,650 to 9,900
Stroke (minimum in.)	6	6
Unit Weight (lb)	4	5-1/2
Envelope Size		
Length (in.)	15	15
Width (in.)	3-1/2	4-3/4
Depth (in.)	2-1/8	2-1/8
Envelope Size (without tongue, and hook, and through bolts)		
Length (in.)	8	8
Width (in.)	2-5/8	3-5/8
Depth (in.)	2-1/8	2-1/8
Proof Load (lb)	3,500	7,000
Proof Time (sec)	30	30

The Van Zelm Associates Co. (VZA), Entwistle Corp., of Providence, Rhode Island, is involved in considerable design and development work with single cycle load attenuating devices. Their designs have utilized the bending of wire (similar to the developed concept shown in Figure 24), flat sheets of metal, bars, and tubes. Some of their development work and applications are shown in Table VI. A typical performance curve for a 5K cargo tiedown load limiter is shown in Figure 27 (from a VZA report, Reference 28, for the unit shown in Figure 28).

The Air Crew Equipment Department of the Naval Air Test Center is using a VZA designed load attenuation test rig which uses a bar bending concept with a total load capacity for 80 units of 60,000 pounds. Figures 29, 30, and 31 show other concepts that have been reduced to actual hardware (Reference 29).

TABLE VI. SUMMARY OF LOAD LIMITER HISTORY (VZA)

Load Limiter	Resistance (lb)	Stroke (in.)	Weight (lb)	Remarks and Uses
LL-1	-	-	-	LL-1 and LL-2 evolved into LL-3 design
LL-2	-	-	-	
LL-3	2,500	4	0.34	USN pilot seat load limiter
LL-4	750	12	0.10	Seat belt load limiter
LL-5	5,250	+3**	1.60	NASA pilot seat load limiter
LL-6	1,000	12	0.23	Litter mounting load limiter
LL-7	4,000	24	1.60	Gas tank tiedown
LL-8	2,400	36	-	Catapult acceleration limiter
LL-Compression	2,000	8	0.34	Troop seat or vehicle shock limiter strut
LL-9	650	72	0.6	Troop repelling line load limiter
LL-10	2,400	43	-	Airborne litter load limiter
LL-11	5,000	24	1.75	Air cargo load limiter
LL-12	11,000 lb for 48 in. Decreases from 11,000 to 0 lb from 48 in. to 120 in.	120	-	Fast highline trolley load limiter
LL-14	5,000	12	1.4	Air cargo load limiter
LL-15	10,000	12	2.7	Air cargo load limiter

NOTES:

* Strokes are for the particular designs. This dimension is easily varied to suit other applications.

** LL-5 is designed to travel 3 inches in either direction. It is capable of limited repeated cycling.

*** Decreases from 11,000 to 0 pounds from 48 to 120 inches of stroke.

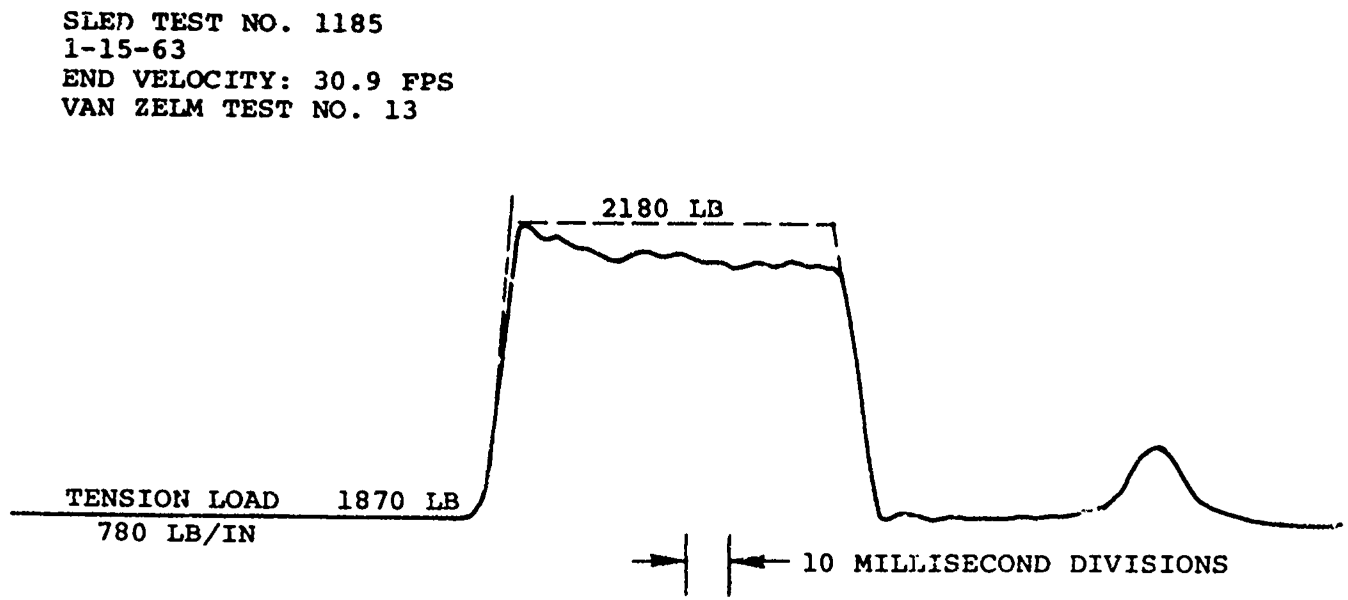


Figure 27. Performance Curve for Metal Tape Bending Device (VZA).

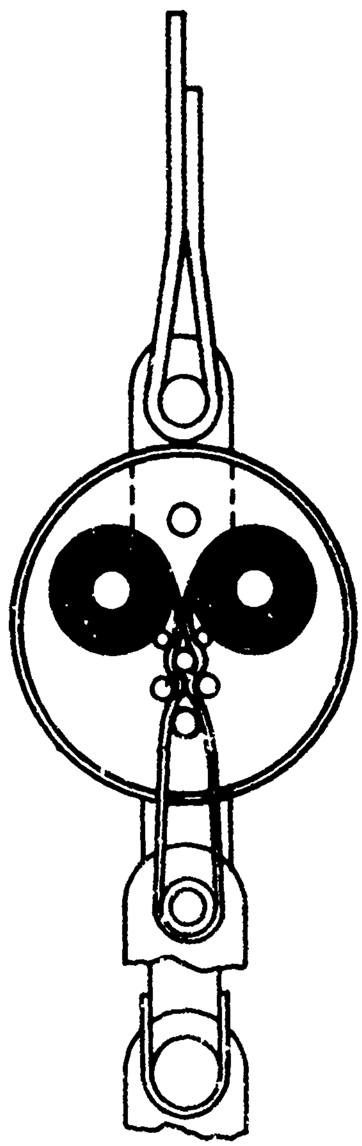


Figure 28. Metal Tape Bending Device for Load Attenuating (VZA).

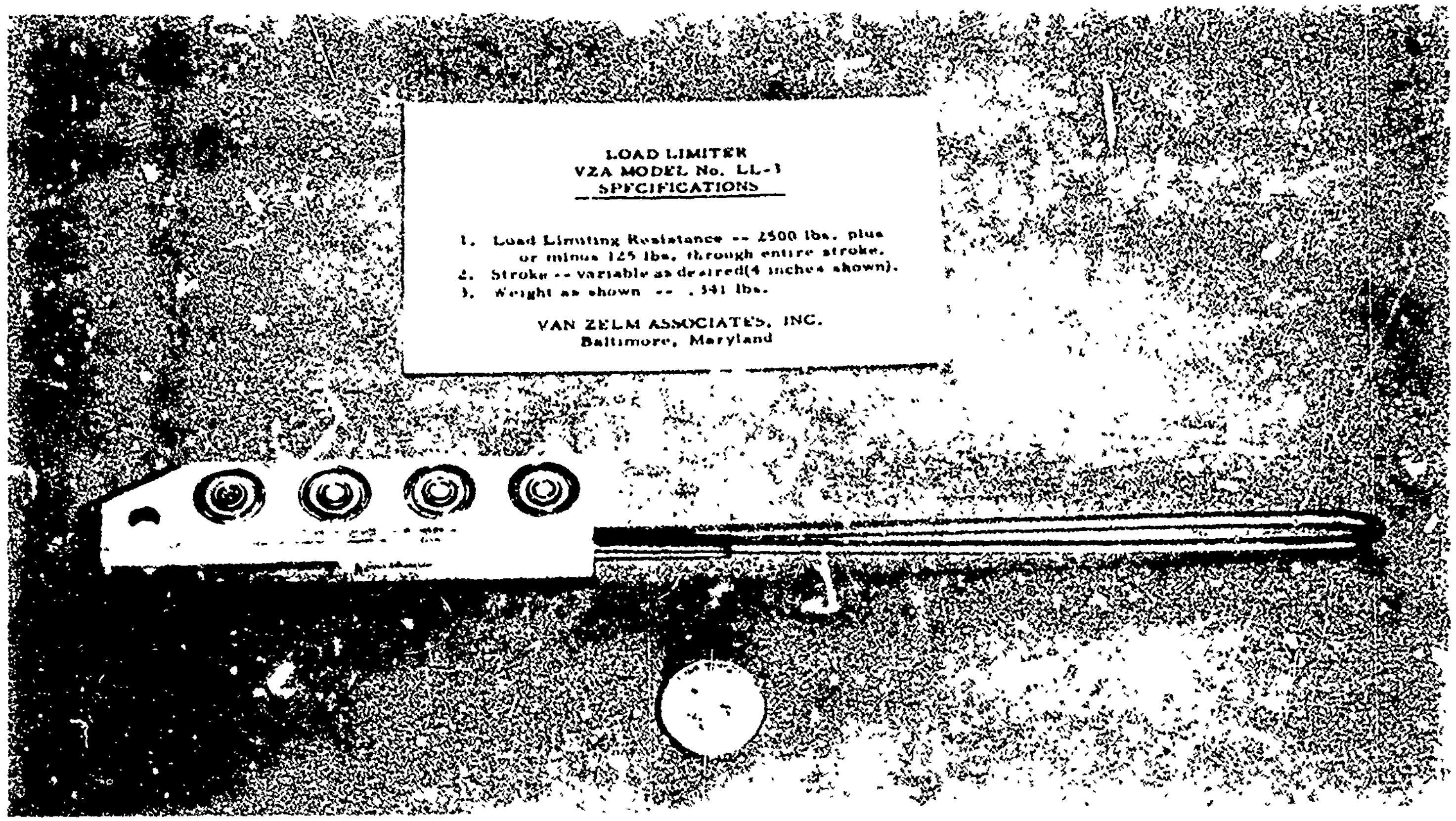


Figure 29. Model LL-3 Load Limiter (VZA).

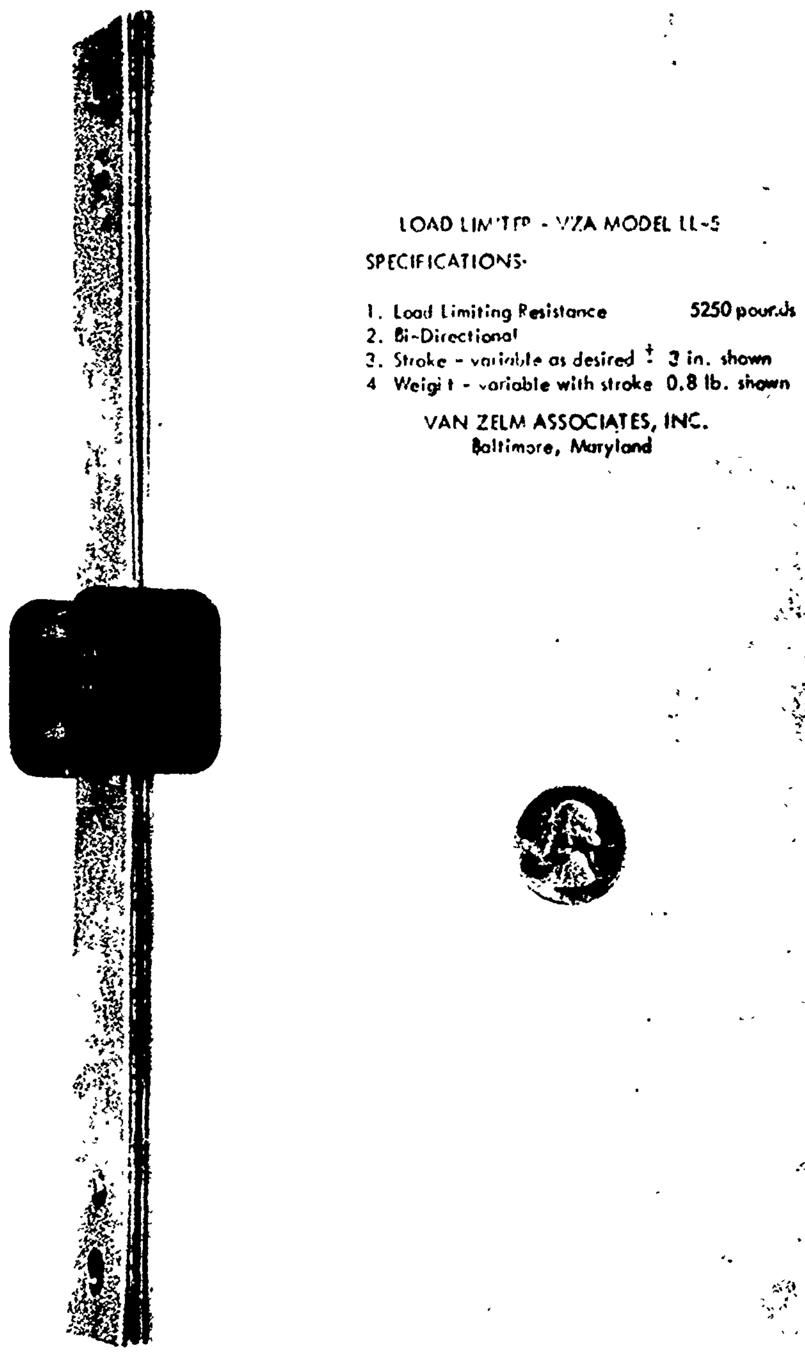


Figure 30. Model LL-5 Load Limiter (VZA).

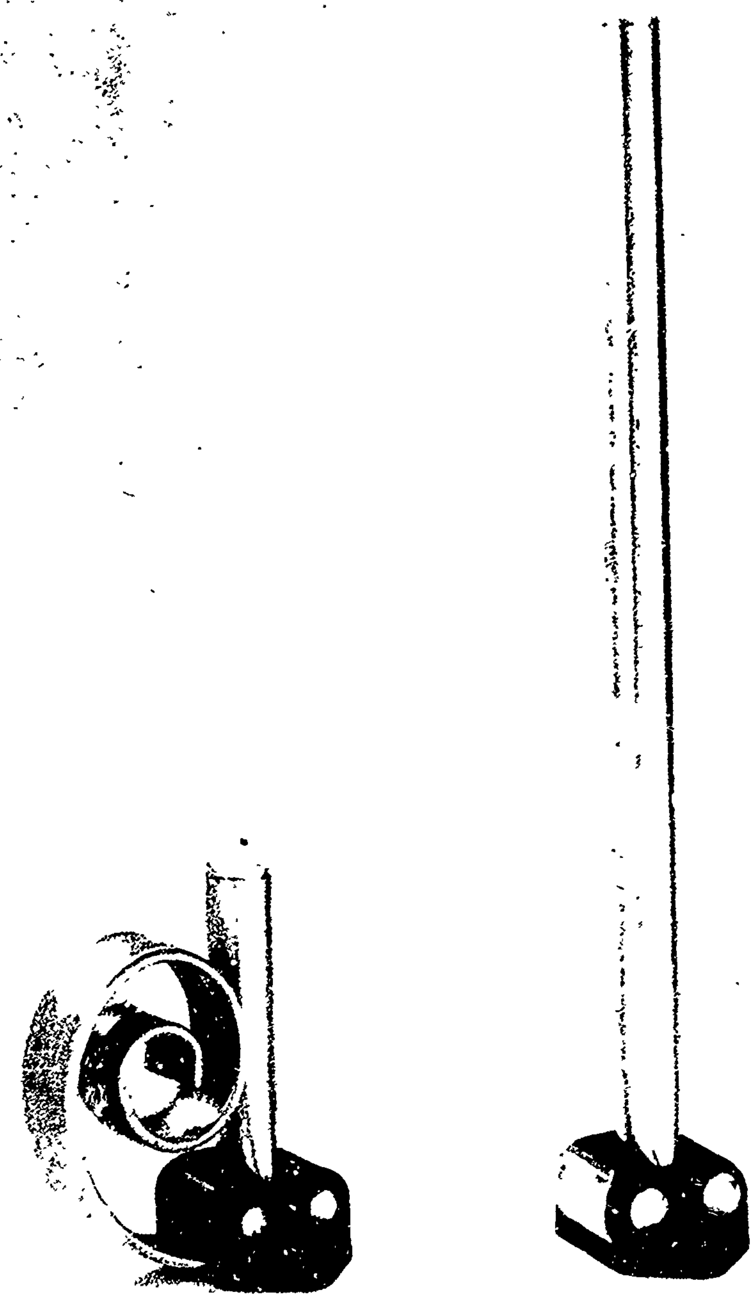


Figure 31. Compression Shock Strut, 2000-Pound Capacity (VZA).

From the pulse curve of Figure 27, the attenuator load decreases nonlinearly with increasing stroke time. The largest decrease in load is realized for a short duration at the beginning of the stroke with the load intensity tending to level as the stroke increases. It is estimated from the curve that the load limiter impulse momentum response or efficiency is about 91 percent of an ideal load limiter concept (shown by a dashed line).

Multicyclic Plastic Deformation

Mechanics Research Incorporated (MRI) has been developing a device that absorbs energy through multicyclic plastic deformation of a ductile metal (Reference 30). This is done by rolling a series of ring elements supported on toroidal retainers and compressed between concentric tubes (see Figures 32 and 33). A typical force-time characteristic curve of the design concept, Figure 34, depicts a relatively level load intensity during the stroking interval.

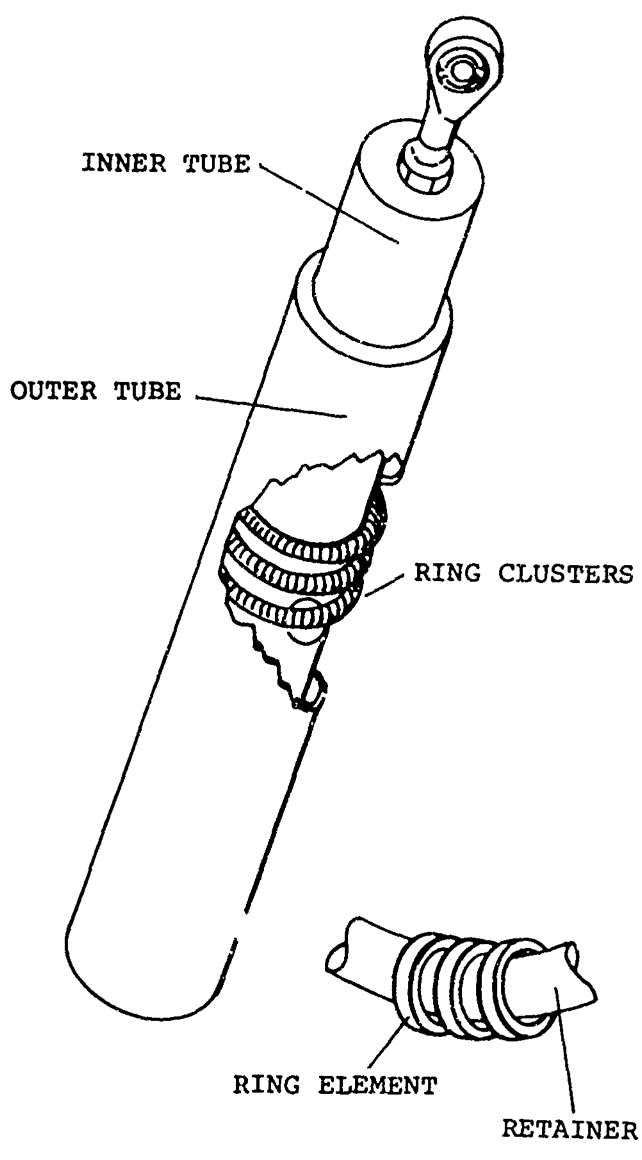
MRI has indicated that a 5,000-pound 6-inch stroke cyclic/strain unit could be produced having a 1-1/2-inch OD, a 7-inch retracted length, a 13-inch extended length, and a weight of approximately 1-1/4 pounds. The device would require some additional development to establish these performance limits. High values of specific energy publicized for the MRI springs (see Section 2.3, ENERGY ABSORBING MATERIALS) are values for the material and are based on low-cycle fatigue criteria. Values for a packaged unit are given in Table IV.

Collapsible Tubes

A wide variety of collapsible tube concepts for energy absorption exists. These include peeled, tube-ball, frangible, tapered, and sealed collapsible tubes.

Two of these concepts, the peeled tube and the tube-ball, are relatively simple and have been evaluated by Boeing and AAE, respectively. The peeled tube design, Figure 35, uses a tube forced over a hardened metal flared die to absorb energy. At a predetermined load, the tube begins to split and peel back, as shown in Figure 36. This principle can be used for either tension or compression strut applications.

The Naval Air Material Center has tested a new design furnished as a test specimen by Boeing that is similar to an earlier installation made in the ACH-47 Armed Chinook (see Figure 37, from Reference 31). Figure 38 shows this new strut being tested in the VZA test rig, and Figure 39 shows an instrumented drop test curve of its performance (Reference 52). Figure 40 shows a possible application in the CH-47 helicopter.



PATENT APPROVED

Figure 32. Rolling Ring Strut Energy Absorber (MRI).

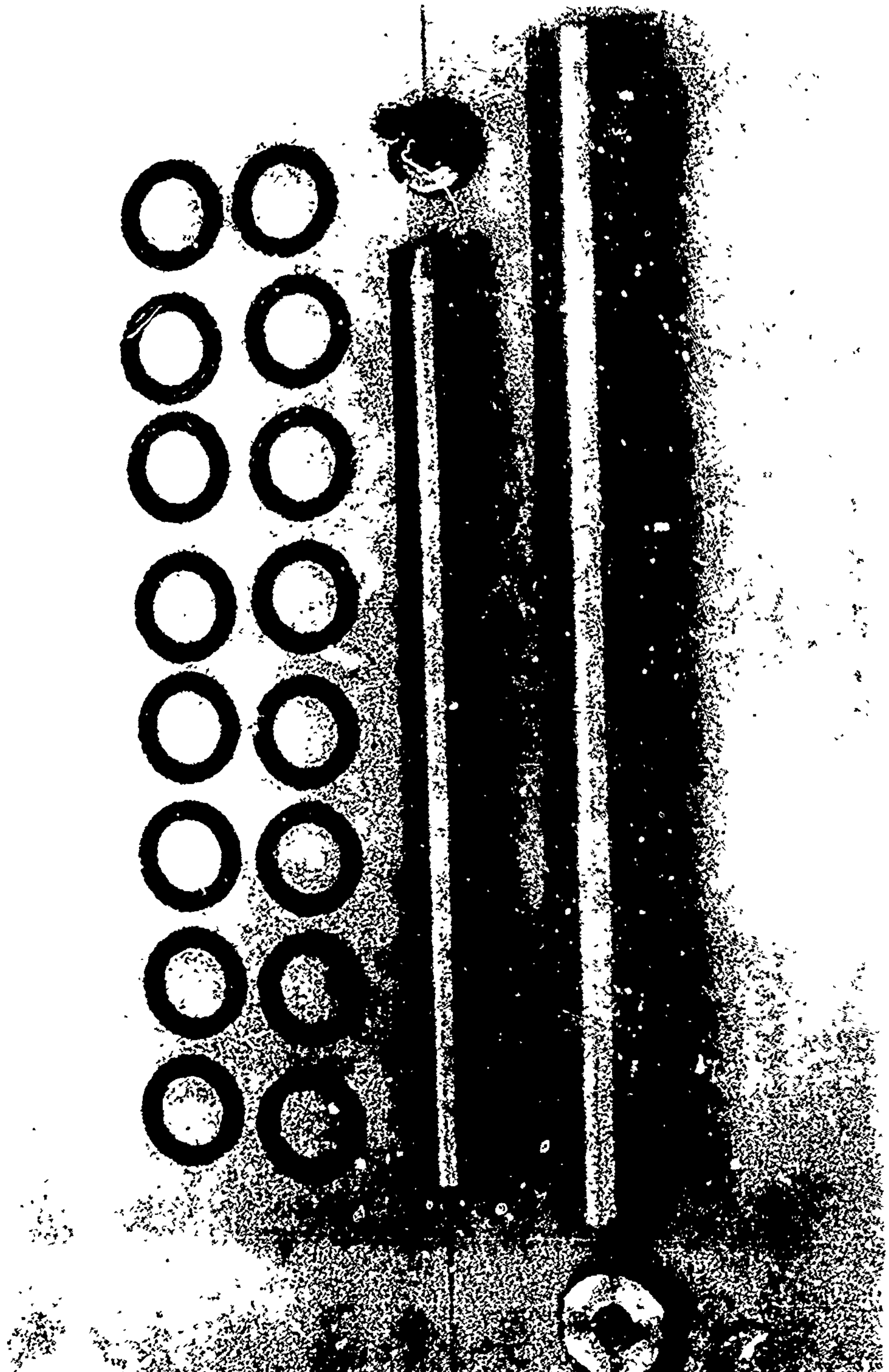


Figure 33. Disassembled Rolling Ring Strut Components (MRI).

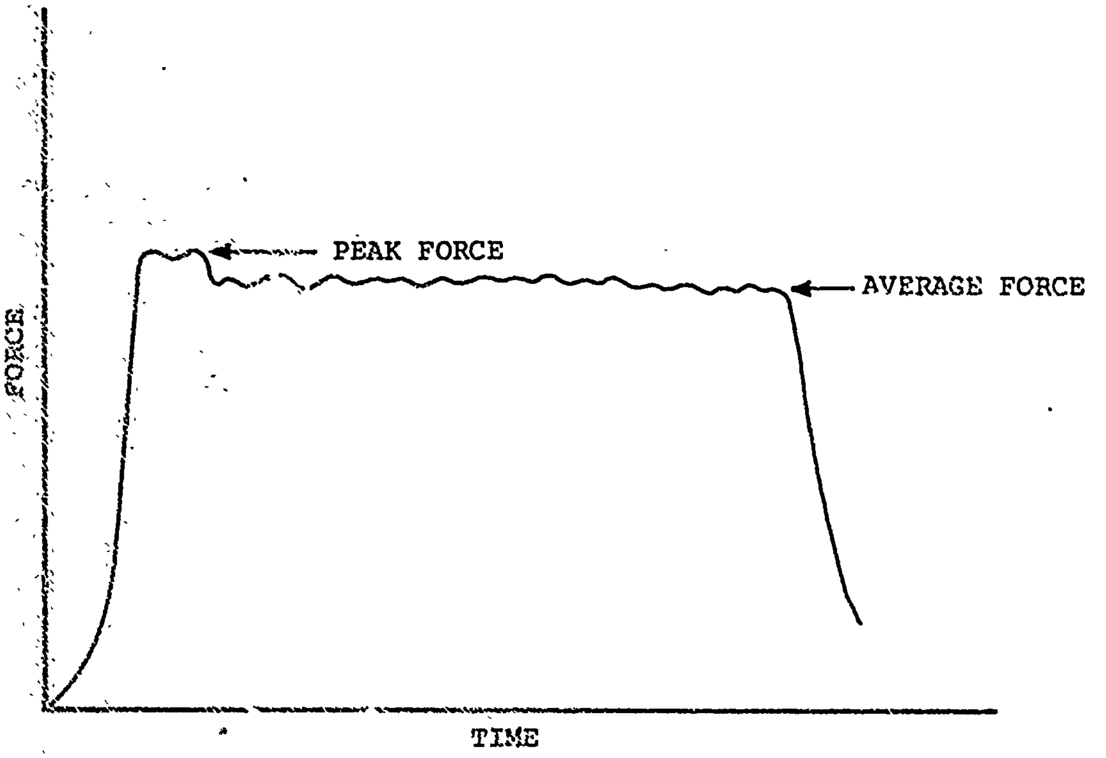


Figure 34. Characteristic Force-Time Behavior (MRI).

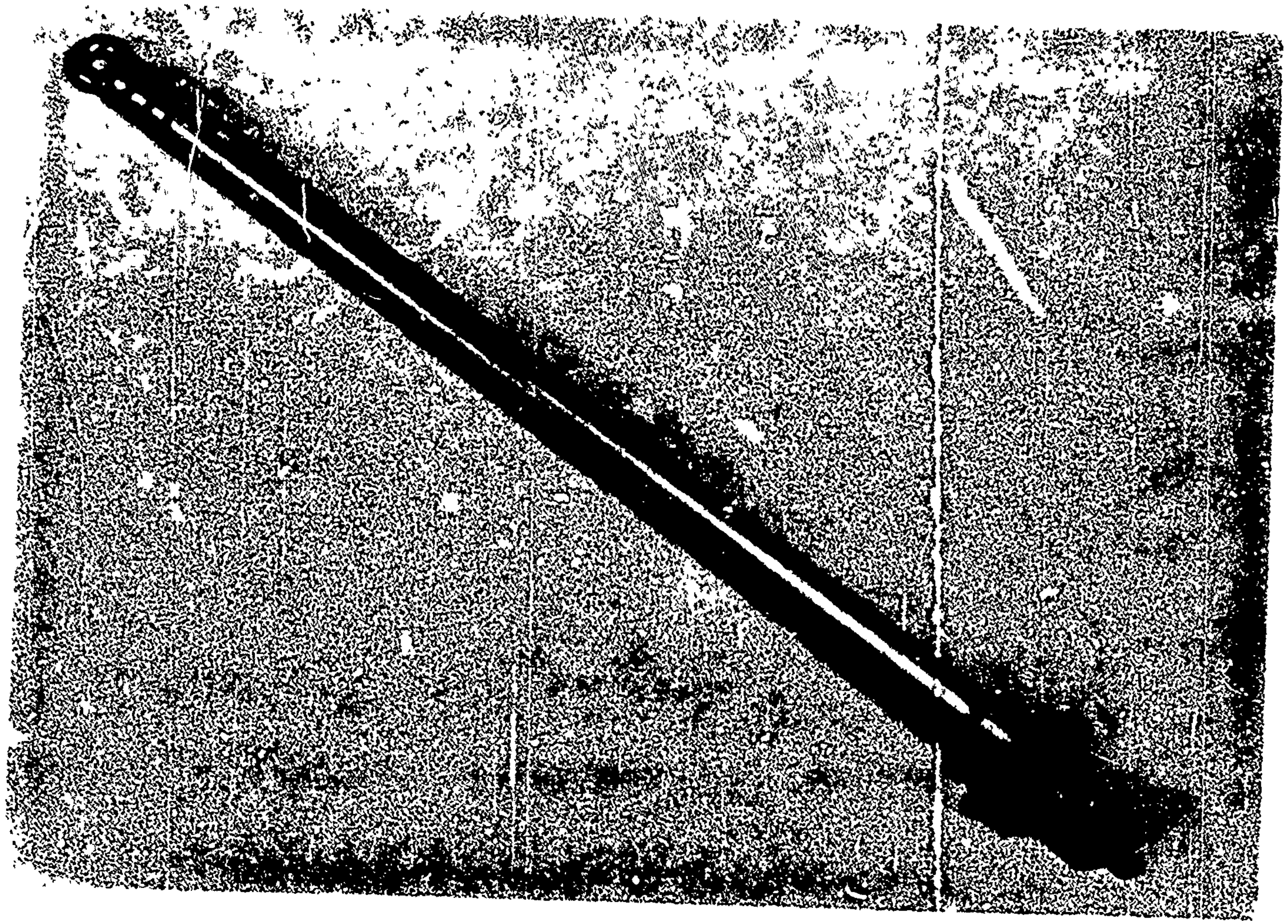


Figure 35. Boeing Compression Peel Strut for Crew Seat Support, Before Peeling.

Figure 36. Boeing Tension Peel Strut Load Limiter, After Peeling.

Figure 37. Boeing Peel Strut Load Limiter, Part No. 143ES003-1, Used with CH-47 Armored Seat.

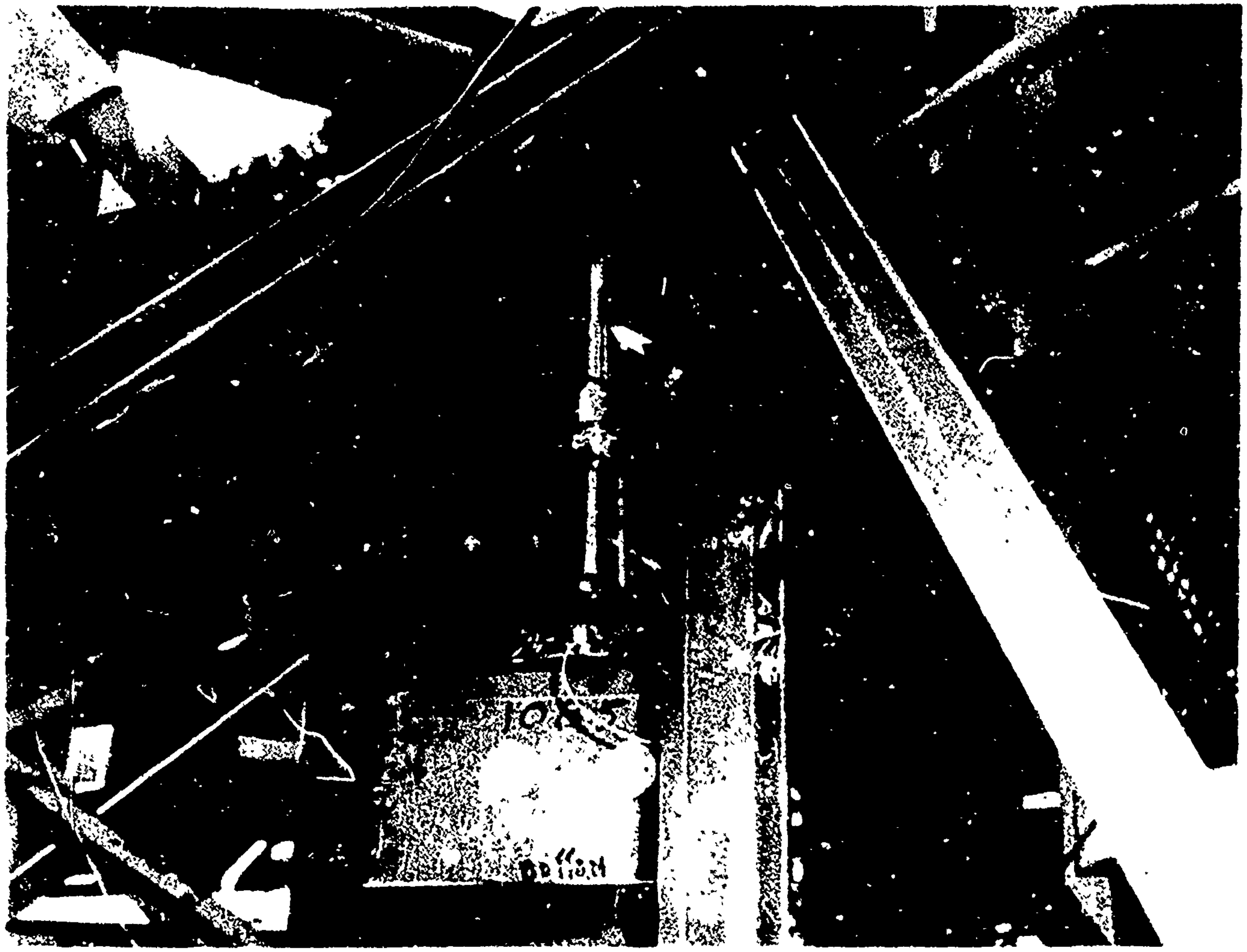


Figure 38. Boeing Tensile Peel Tube Strut in Test Rig at ACED, NAMC.

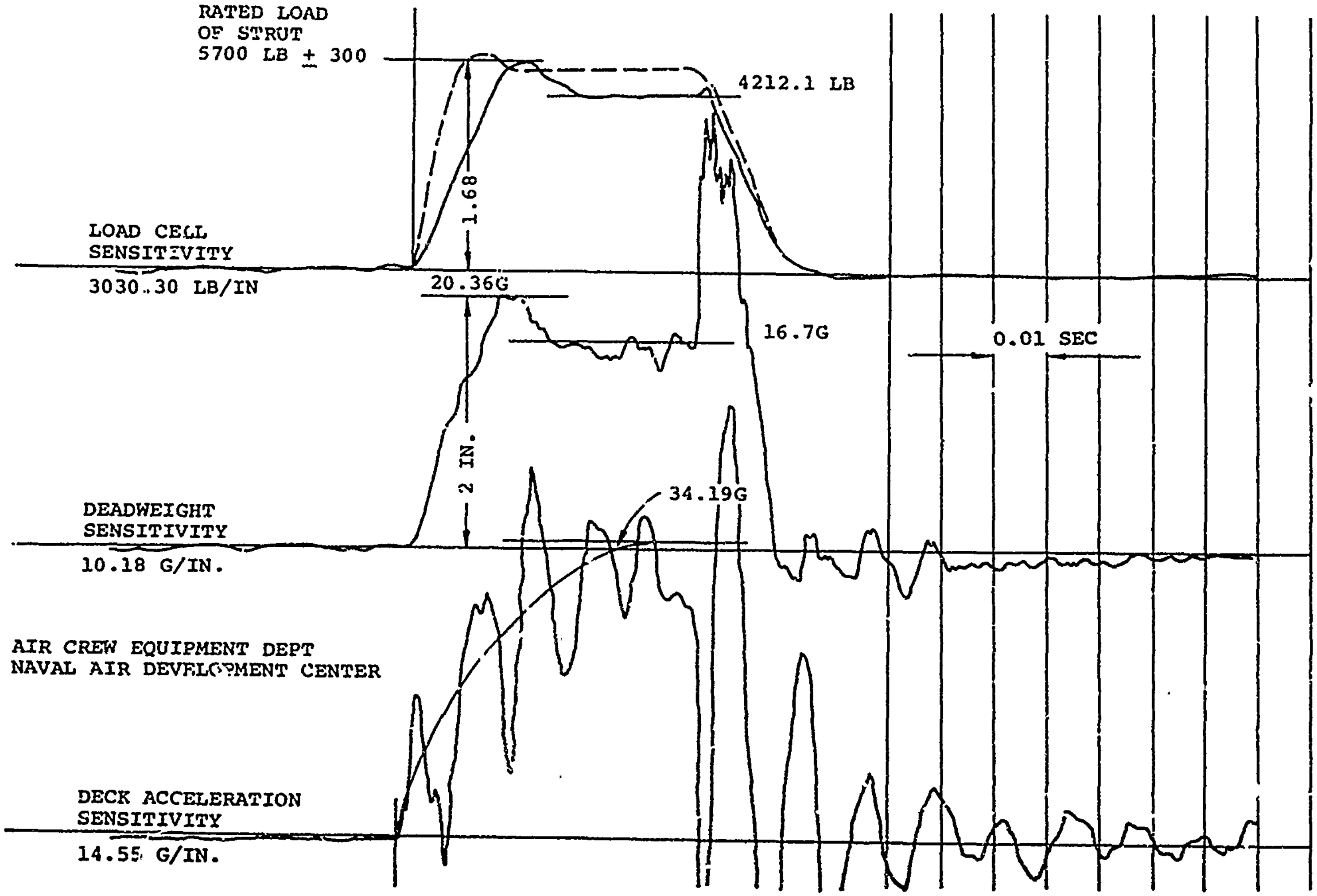


Figure 39. Performance Curve of Boeing Tension Peel Strut.

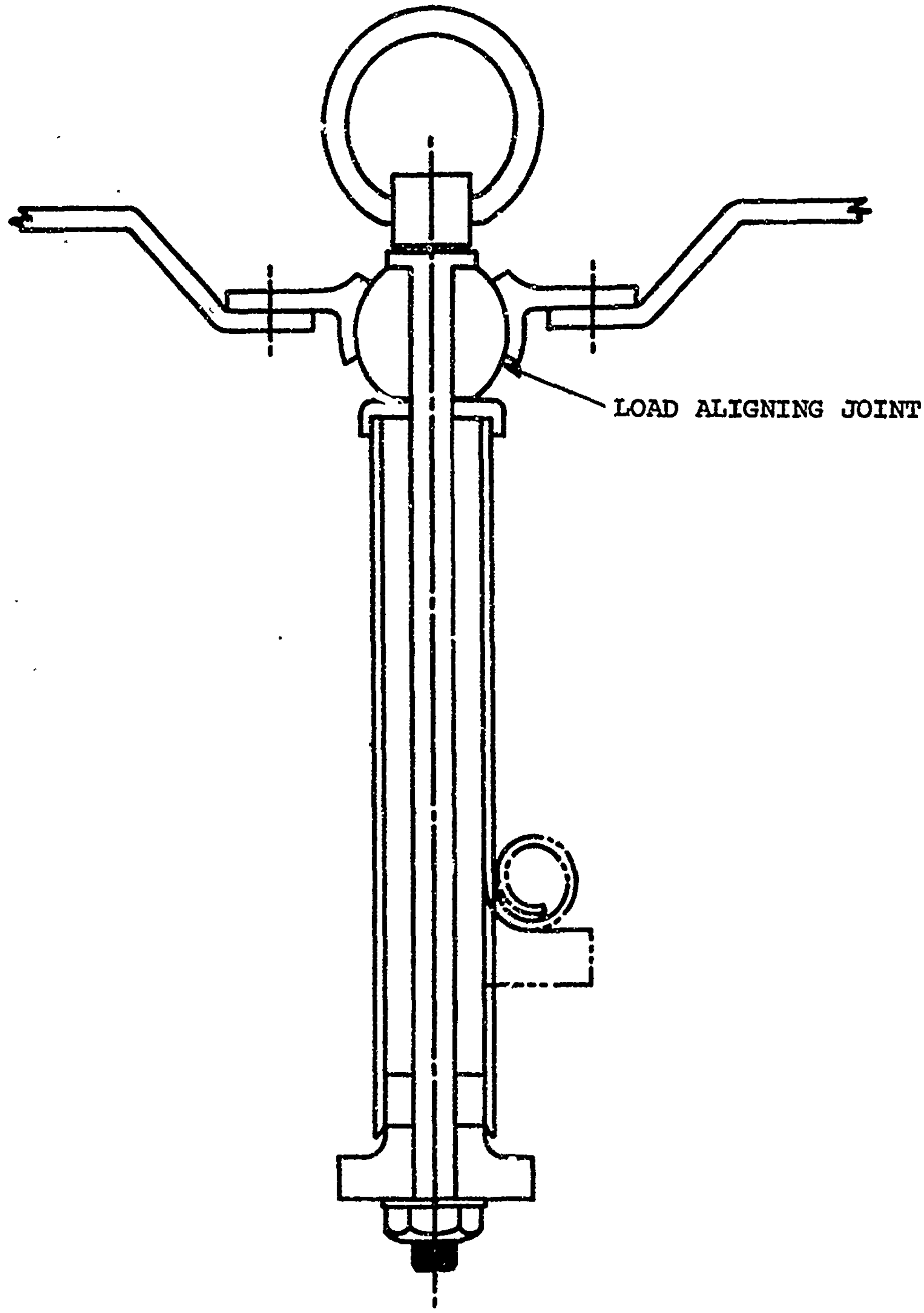


Figure 40. Split-Tube Tiedown Energy Absorber.

The solid line of the curve in Figure 39 shows initial peak load with an approximate 20 percent drop-off in load level. The peak load can actually be eliminated by prestressing during fabrication of the units. In addition, load attenuation of 5,000 or 10,000 pounds can be easily attained with a minimal amount of development. The anticipated load-time curve is represented by the dotted curve in Figure 39. A greater rate of onset can be expected when used for cargo attenuation than is shown by the existing test data. This is attributed to the fact that the rate of load application during crash events will be greater than that obtained during the test events.

The high peaking action shown for the deadweight load time curve was obtained from a stop placed in the test setup to prevent further stroking of the device. This explains the increase or peak load at the end of the constant load level of 4212 pounds (shown as a solid line).

Figure 41 is an alternate application of the metal peeling idea in the destruction of the CH-47 floor tiedown rails. Excessive restraint loads to the cargo rings would split the rail structure in a manner similar to a tube. The slots in the rail reduce the breakout force. This concept would utilize an aircraft part as the working medium to reduce weight over a separately packaged load limiter.

Boeing has demonstrated the metal peeling principle in crash tests at AVSR and installed a peel tube in the ACH-47 helicopter for seat strut and other applications. Figure 37 shows a possible configuration adaptation for the CH-47 helicopter tiedown arrangement.

Boeing peel-struts have been built in limited quantities for test. Part No. SK18595 tension strut (Figure 38) in quantities of eight were priced at $247.00 each. Part No. SK18586 compression strut in quantities of four had a unit cost of $191.00.

The tube-ball principle, shown in Figure 42, has been proposed by All American Engineering. Subsequent to the work covered by Reference 6, AAE built and tested a new short stroke design. Pull tests are indicated as very consistent and manufacturing problems relatively easy to control. However, within the contract time schedule, no performance data was obtainable from AAE for this concept of load attenuation. (An integral installation of a tube-ball device is shown in Figure 43.)

The frangible tube principle (Figure 44) can also be applied as a load attenuating means (Reference 17). Also, NASA has investigated the use of frangible struts for lunar vehicles

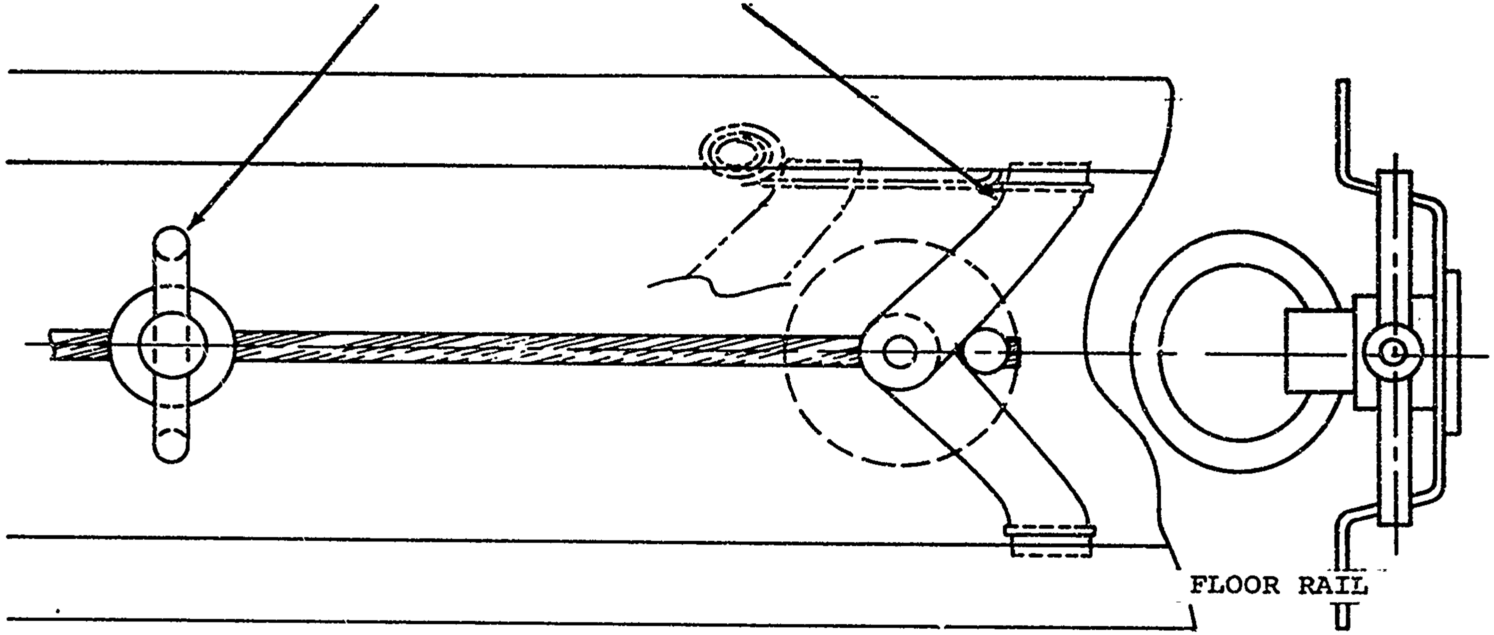
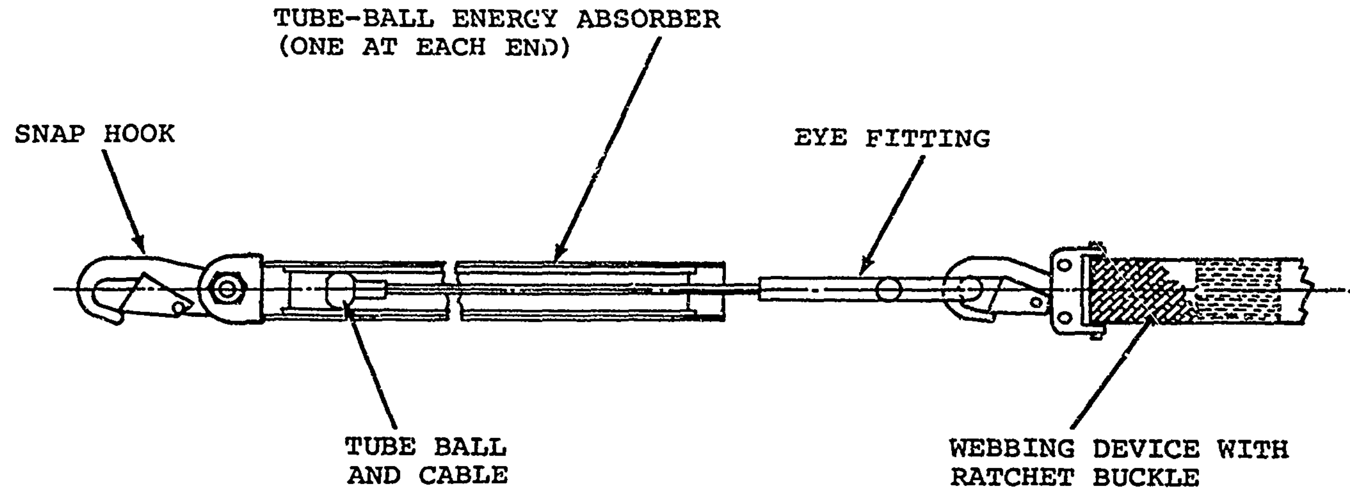


Figure 41. Rail Splitter.



STRAP DEVICE WITH TUBE-BALL ENERGY ABSORBERS

Figure 42. Tube-Ball Tiedown Energy Absorber.

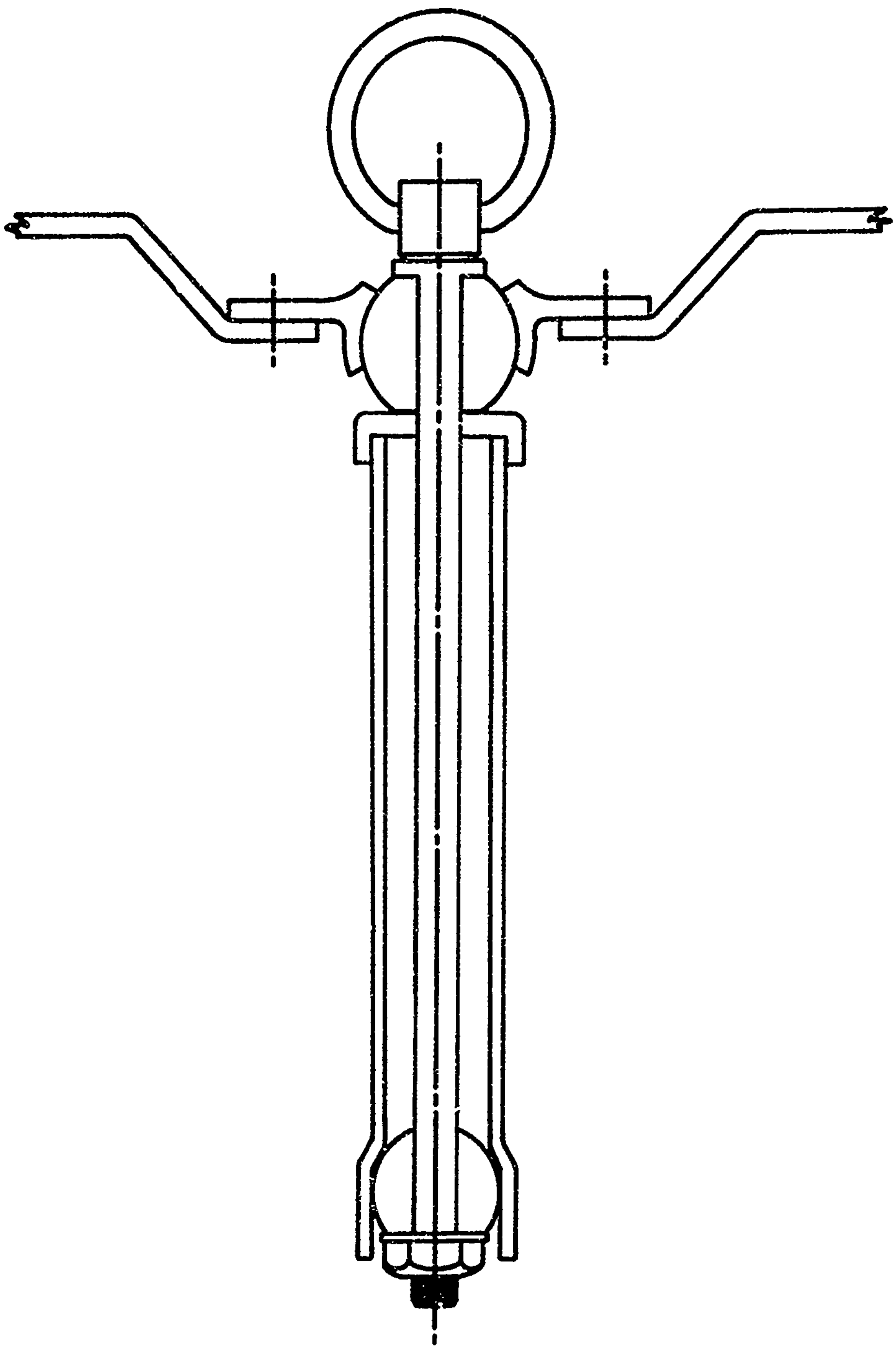


Figure 43. Tube-Ball Energy Absorber (AAE).

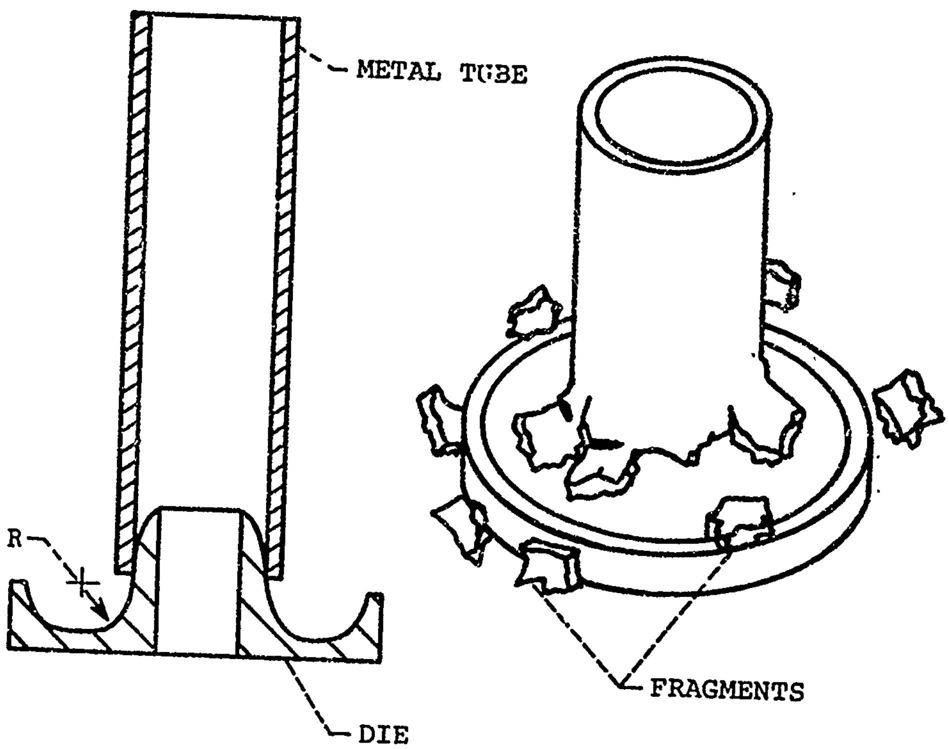


Figure 44. Frangible Tube Device (NASA).

(Reference 32). An objection to using this concept is the possibility of large force fluctuations with the fragments, in effect, becoming shrapnel if not contained in some manner.

Figure 45 illustrates the potential of using a collapsible tapered tube or cone. This concept permits high stroke efficiency in that the collapsed height of the attenuating device would be minimal.

Figure 46, a formed accordion fitting, shows an application of a collapsible tube. As indicated, a preformed shape is collapsed in the normal installation, and when activated unfolds to absorb energy by a combination of unfolding and subsequent elongation of metal. This concept could be adapted to most tiedown rail pans with a flush floor type of installation.

Another concept, the canister or sealed tube, would tend to collapse on itself, as illustrated in Figure 47, thereby absorbing energy as the wall of the tube is upset. Additional restraint could be obtained by having the canister sealed, thereby compressing the trapped air as the tube is deformed.

Plastic Torsional Deformation

The ARDE Company is developing a load attenuation device which uses the plastic torsional deformation of a stainless steel bar. As depicted in Figure 48 when the bar is loaded to a preselected intensity, it will be pulled through a set of three dies causing four 90-degree cycles of twist, thereby providing the required energy dissipation. The load level can be varied by changing the twist angle of the center die relative to the end dies. This device (as originally designed) and a modified version have been tested at ACED as part of an in-house IR&D program established for application to flight crew seat design. Figure 49 shows the test unit in the ACED rig. Figures 50 and 51 show the initial performance curves obtained during the ACED testing of the device.

The unit, as built for 5,000-pound capacity, weighs 4.4 pounds. Its actual capacity, however, is not known as yet, but is estimated by ARDE to be 23,000 pounds.

A potential application of the ARDE device to existing floor tiedown fittings in the CH-47 helicopter is shown in Figure 52.

From discussions with the pertinent ARDE personnel, it appears that the design concept is in the last stage of development, which is geared toward maintaining a more constant load level resulting in reducing the ratio of friction to material deformation.

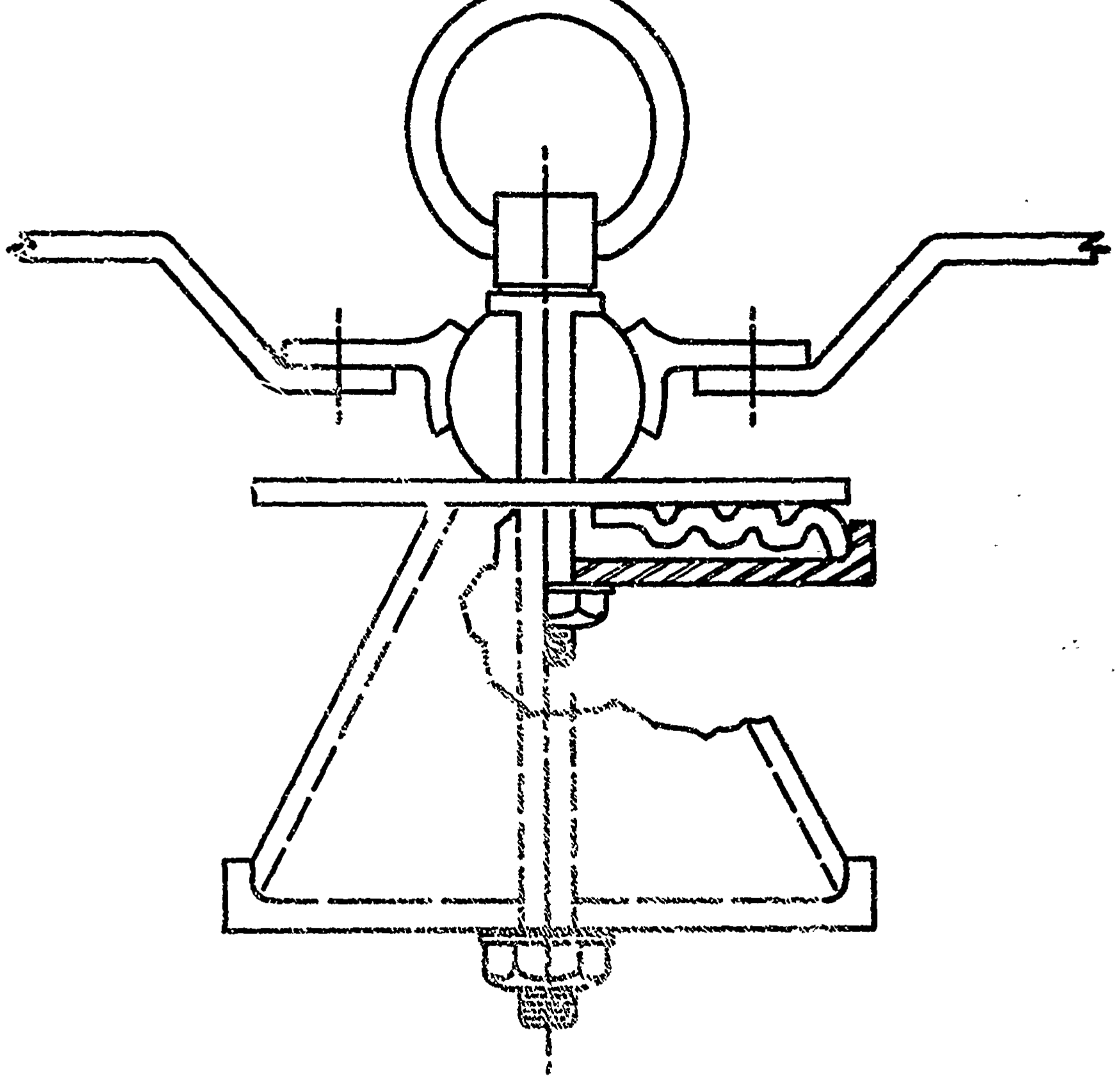


Figure 45. Crushable-Cone Tiedown Energy Absorber.

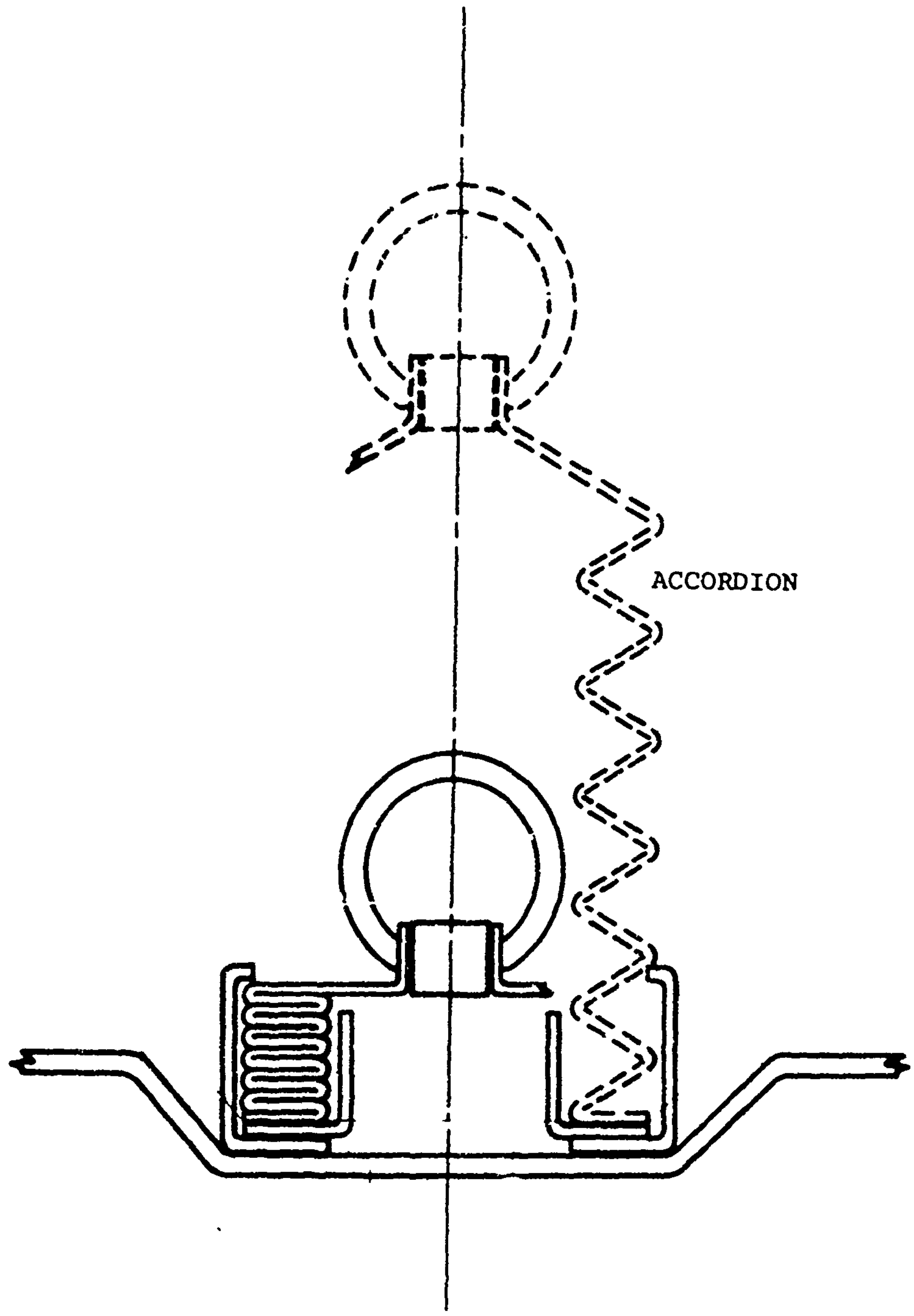


Figure 46. Formed Metal Tube Accordion.

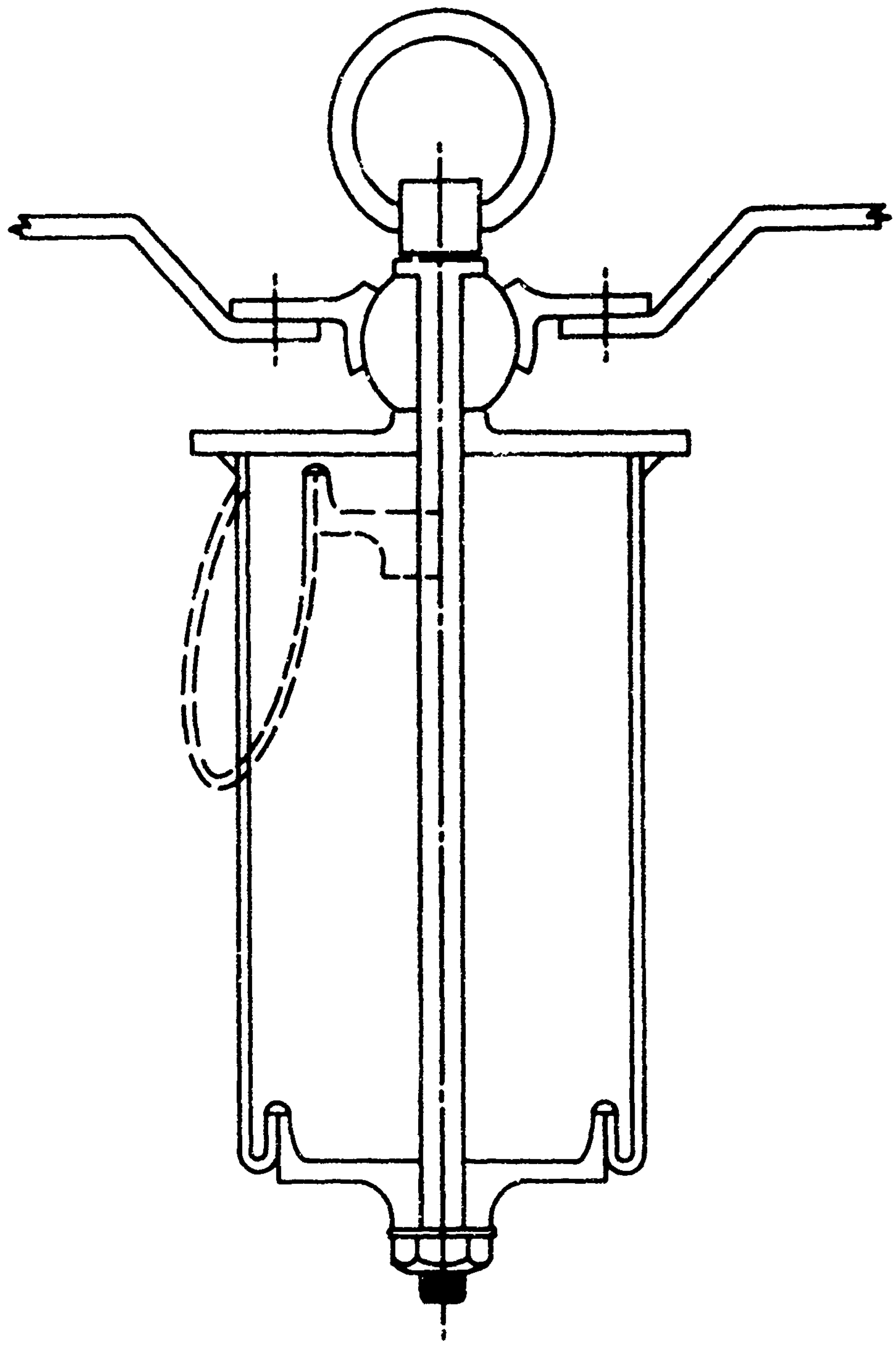


Figure 47. Canister Type Energy Absorber (Atmospheric or Positive Pressure).

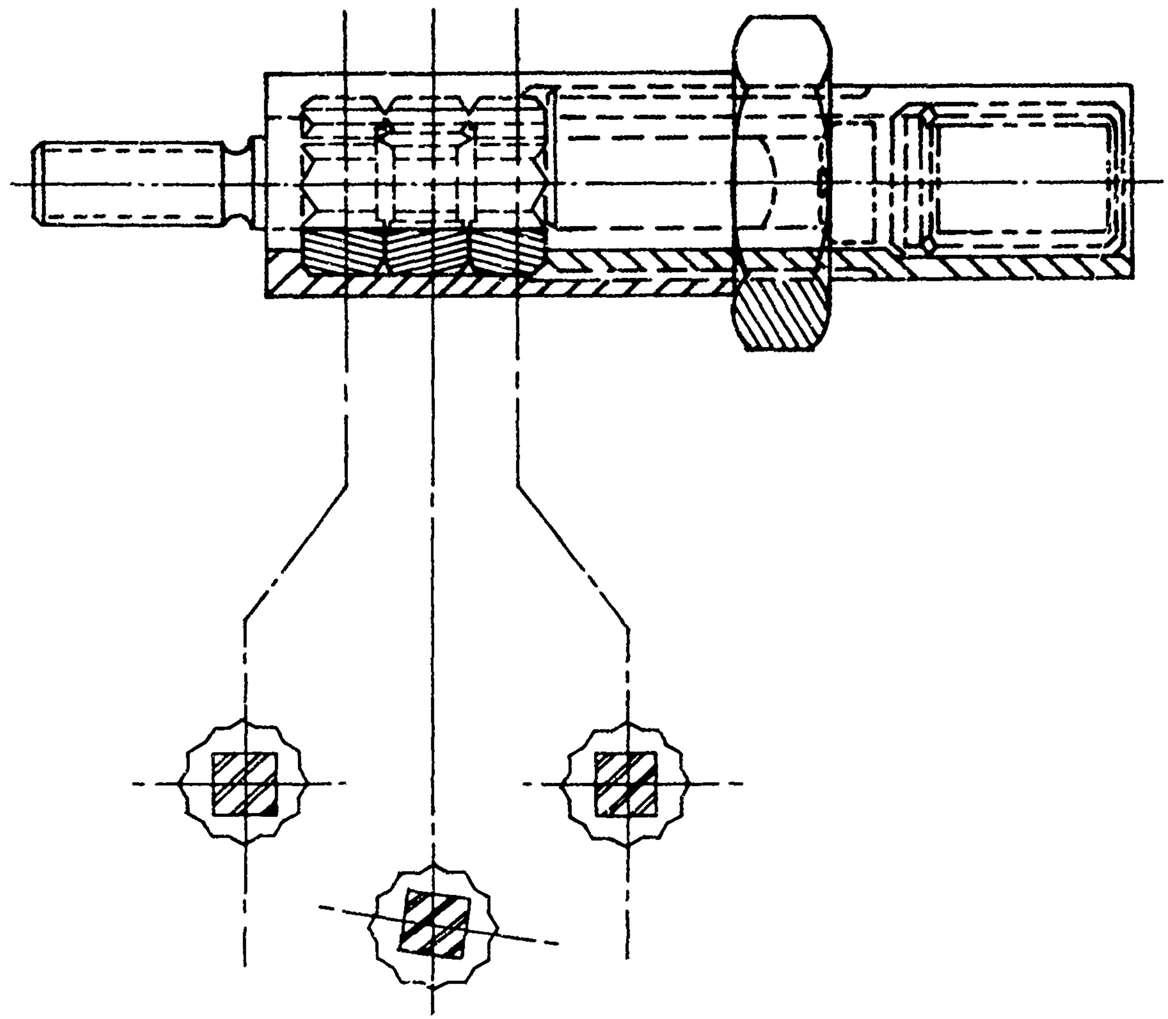


Figure 48. Load Limiter Using Plastic Torsional Deformation of Bar (ARDE).

Figure 49. Load Limiter Device Being Tested at ACED, NAMC (ARDE).

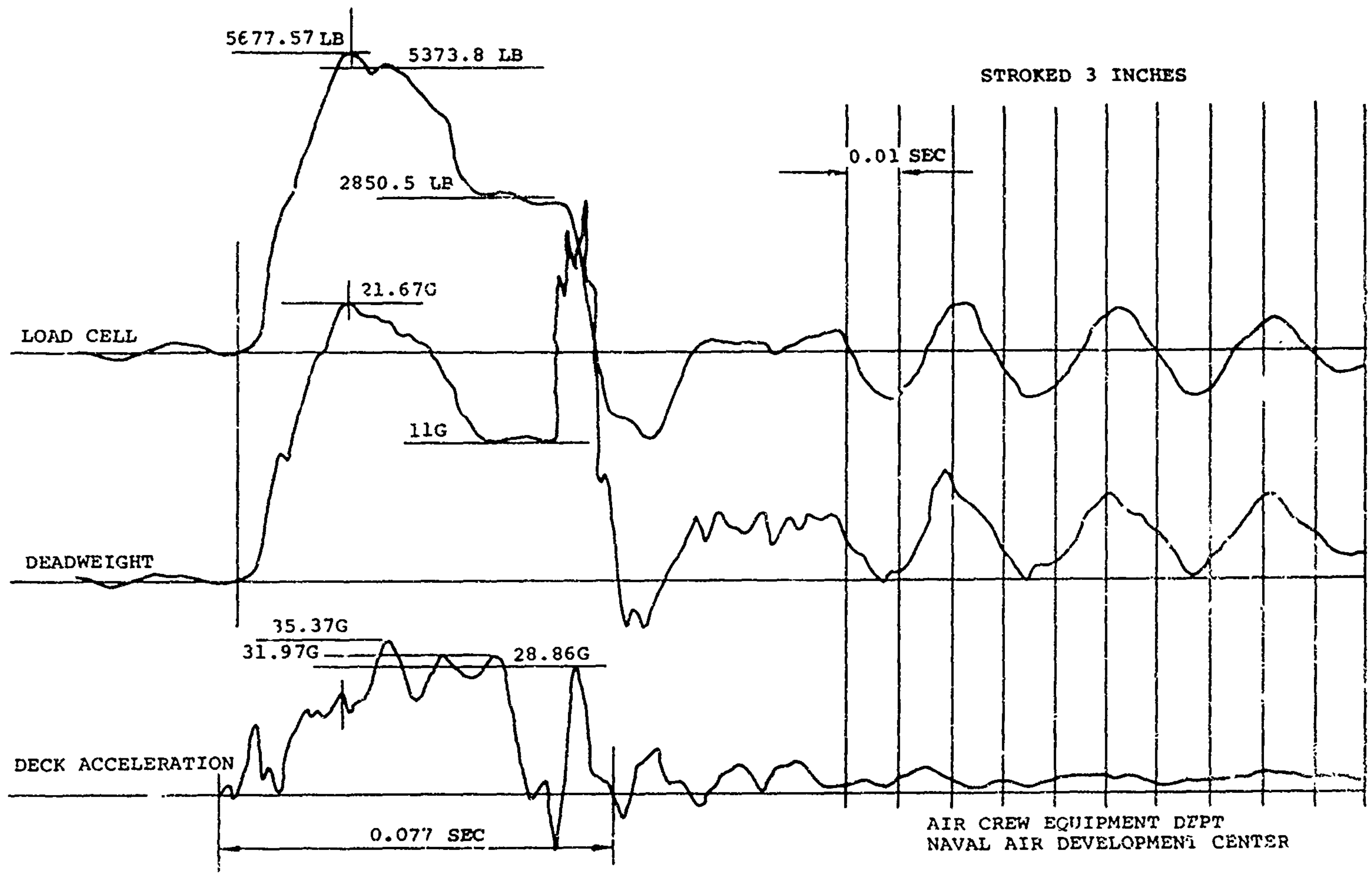


Figure 50. Performance Curve of Load Limiter Using Plastic Torsional Deformation (ARDE).

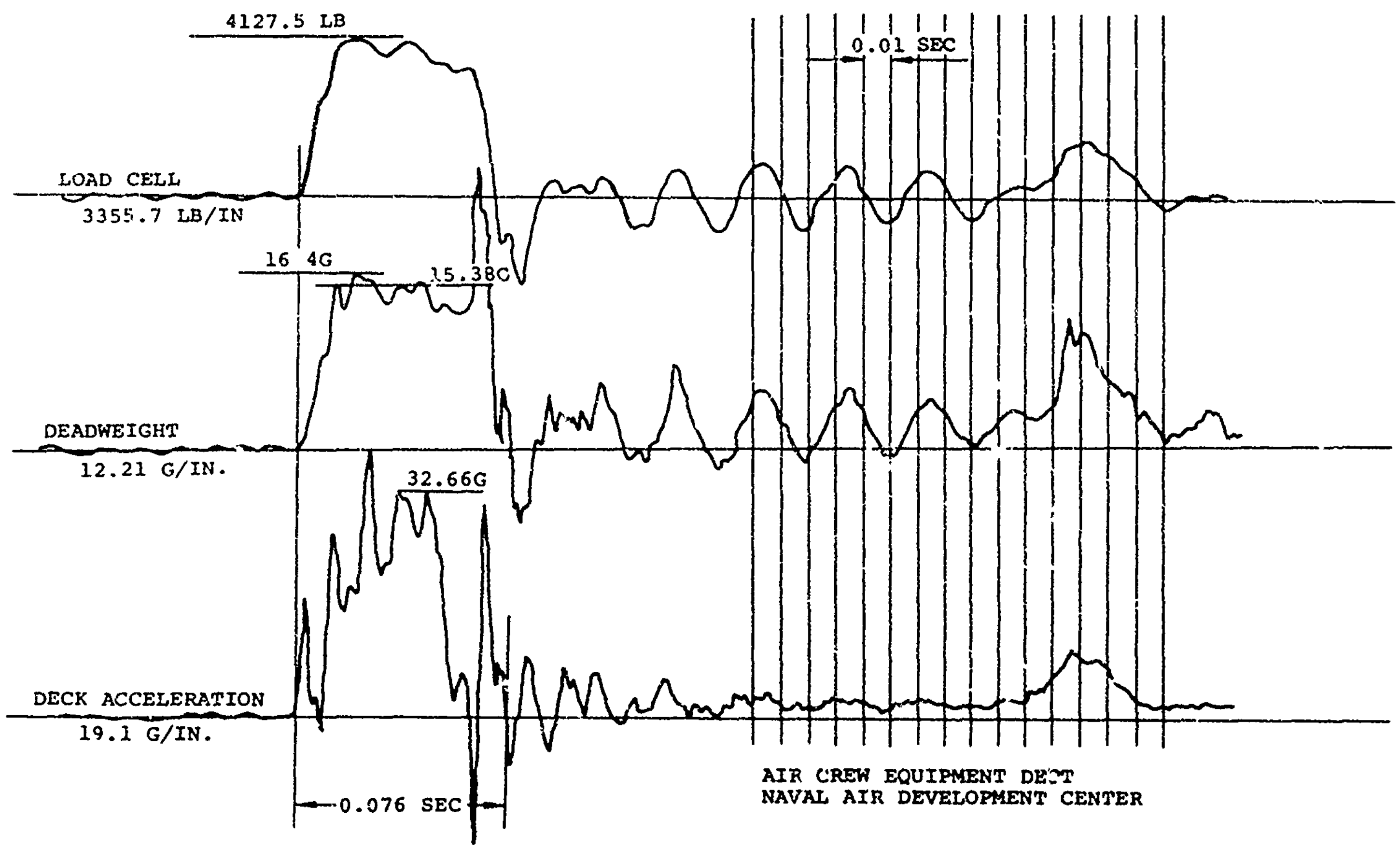


Figure 51. Performance Curve of Load Limiter Using Plastic Torsional Deformation of Fluted Bar (ARDE).

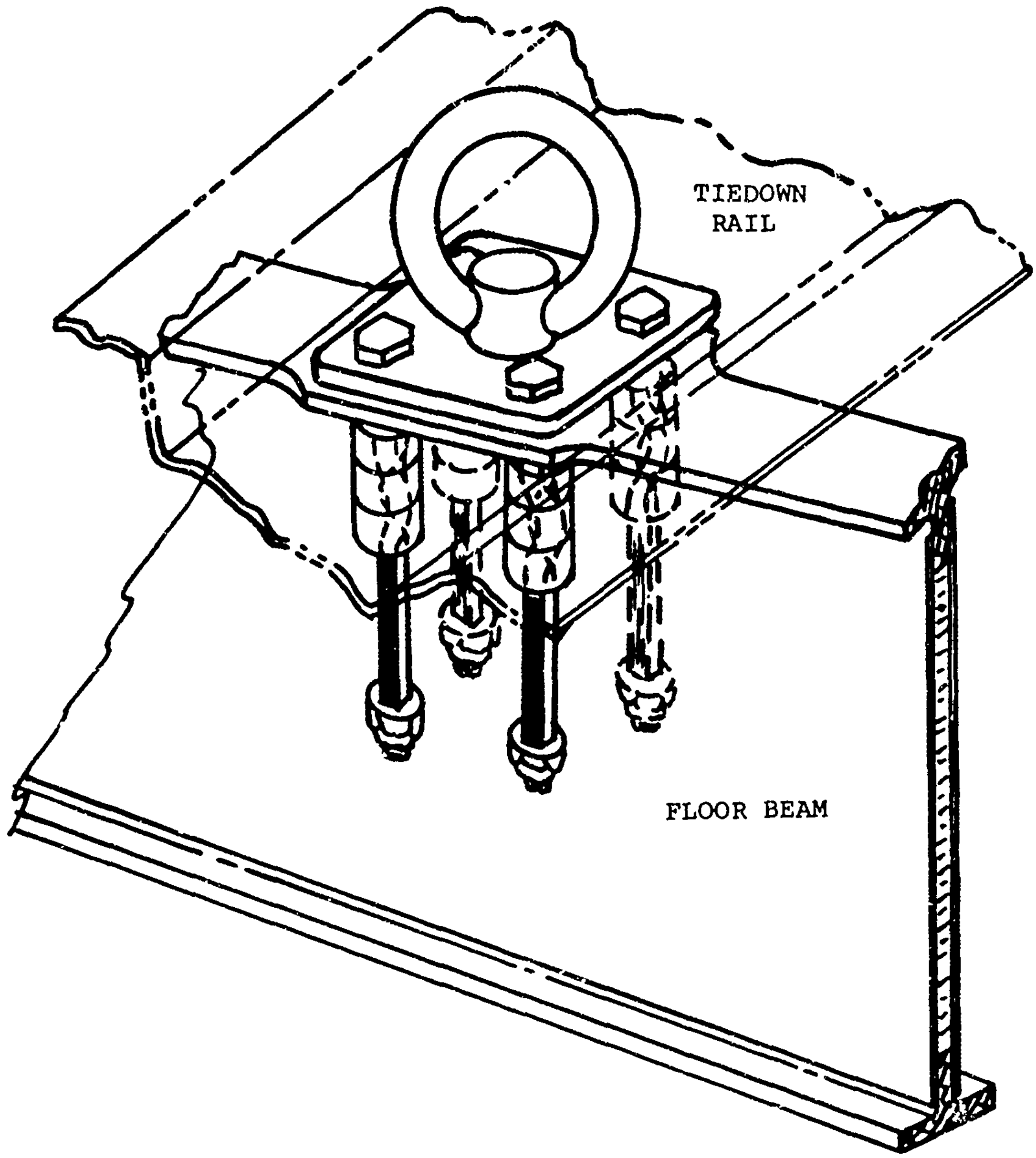


Figure 52. Type Load Limiter Retrofit to Existing Floor Tiedown Fittings (ARDE).

Precrushed Honeycomb

Precrushed honeycomb has been used in many ways to absorb energy; e.g., a single cycle compressible medium in lunar shock struts (Reference 33), landing gear oleo extensions for attenuating high sink rate speeds on helicopters, and seat load attenuation (see Figure 53). Honeycomb material, including glass reinforced phenolic honeycomb (which according to Reference 5 exhibits significantly higher values of average stress and specific energy for comparable densities), could be used for a high-production low-cost energy absorber device. Figure 54 shows a possible application to a tiedown fitting.

In addition, honeycomb could be used between floor and lower skin and structure as a means of reducing cargo floor vertical impact loads. This is illustrated by the test installation shown in Figure 55 (Reference 31).

Annealed Strap and Cable

To reduce crash injuries to pilots, a load attenuator type tensile strap device was developed at ACED for the F7U-3 ejection seat installation. When loaded to a predetermined load, a pair of shear pins fail, allowing a flat annealed stainless steel strap to elongate as a tension member. This is described in Figures 56, 57, and 58 and in Reference 33.

Annealed stainless steel cables were also investigated as a means of snubbing ejection seats, thereby permitting faster pilot separation from the ejection seat (Reference 34).

These two concepts were successfully tested in a Boeing test aircraft (Army designation VZ-2, Boeing Model 76 tilt-wing). (See Reference 35.)

The tensile strap could be used at cargo or barrier net junctions or as an integral part of a web type cargo restraint device, as suggested in Figures 59 and 60. The use of annealed wire cable for nets and barriers would be an alternate design concept. The materials used would have properties similar to those shown in Figure 61 (Reference 34).

The development of Peck and Hale's shock expander clip for strap and net applications could be another alternative. This device is only in the conceptual stage. Figure 62 shows a load attenuating configuration used in series with a wire rope net. This concept could be applied to strap and net tiedown devices.

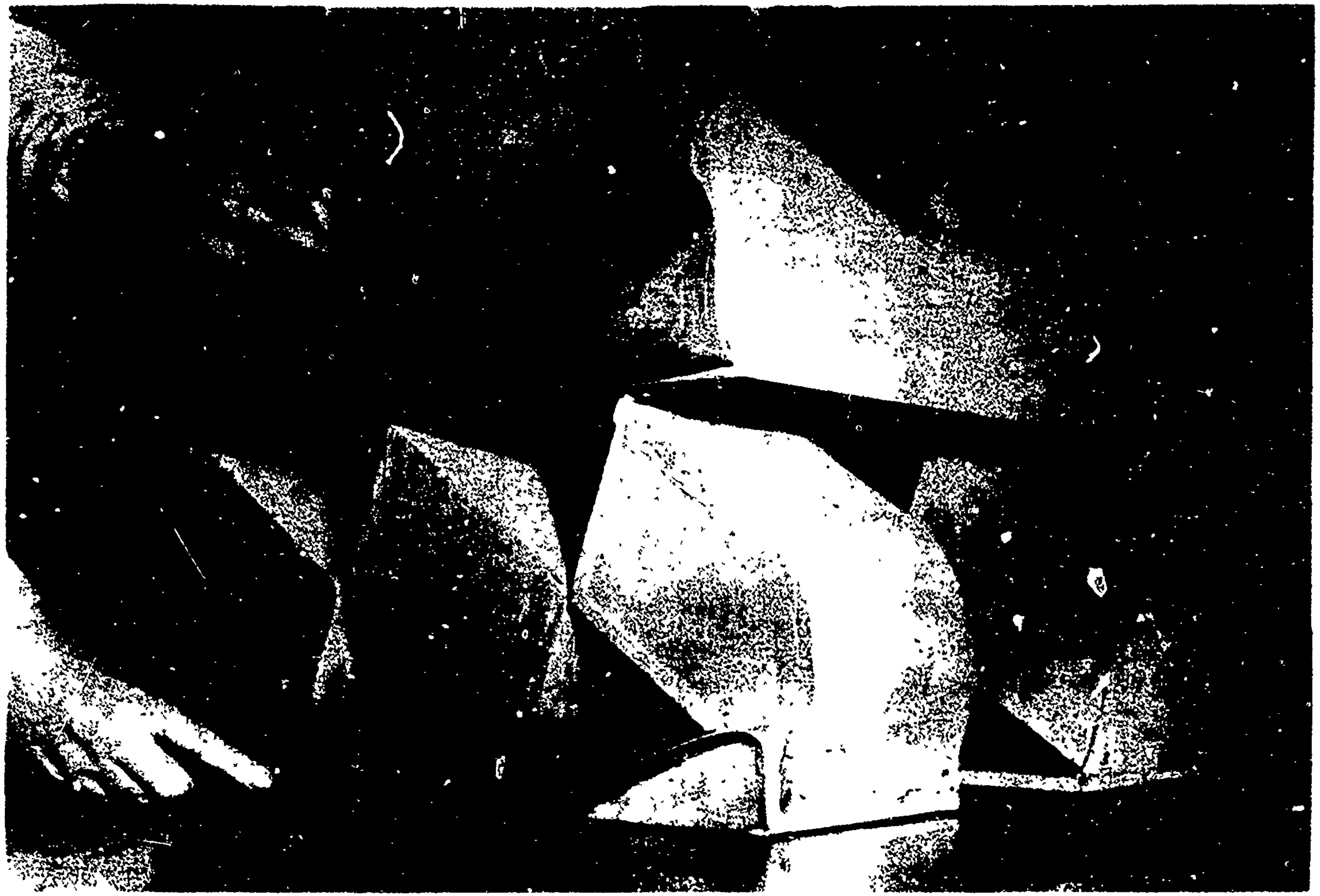


Figure 53. Boeing Honeycomb Construction Load Attenuator Under Seat.

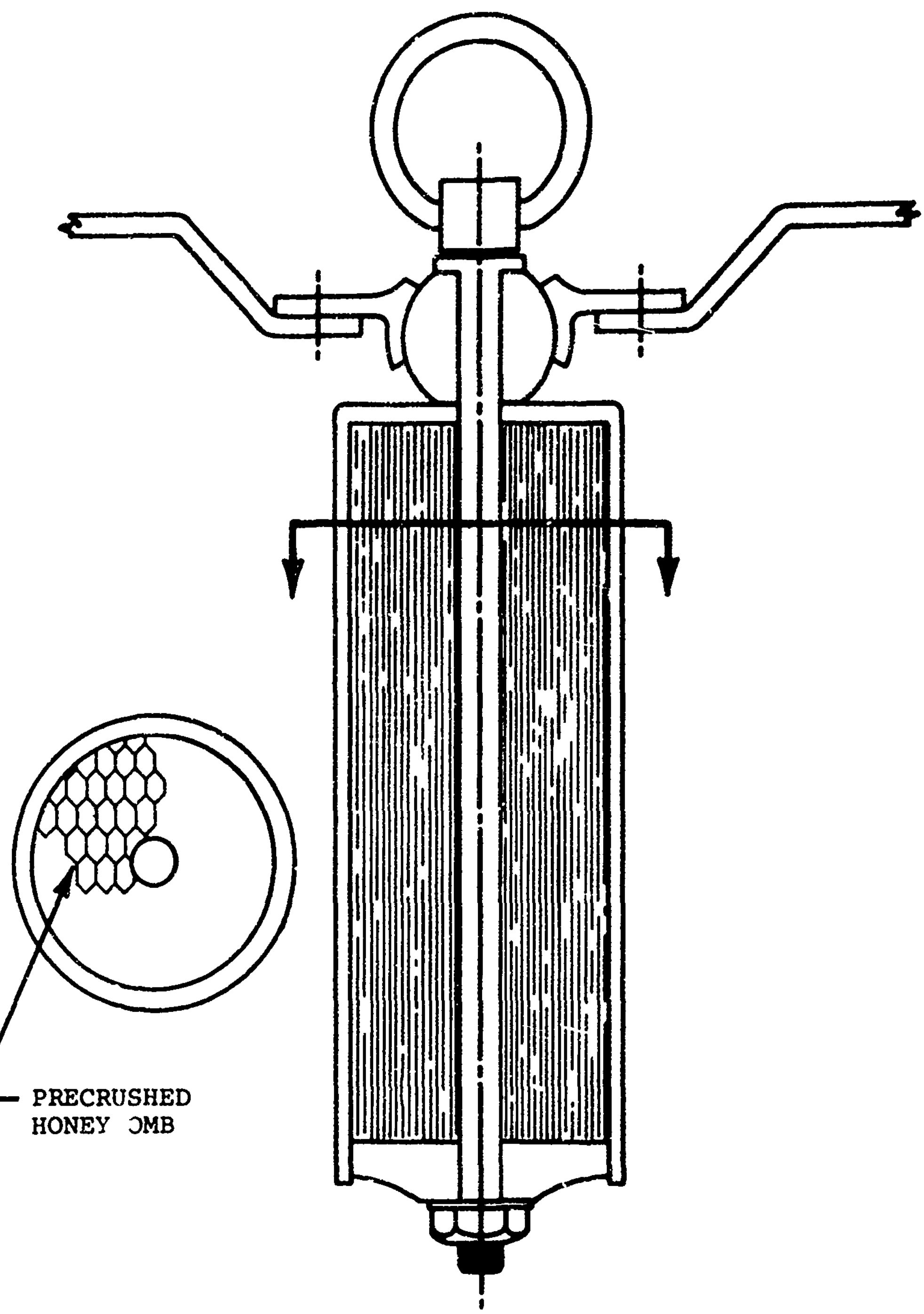


Figure 54. Honeycomb Core Energy Absorber.

Figure 55. Crushable Energy Absorber Pads After Impact.

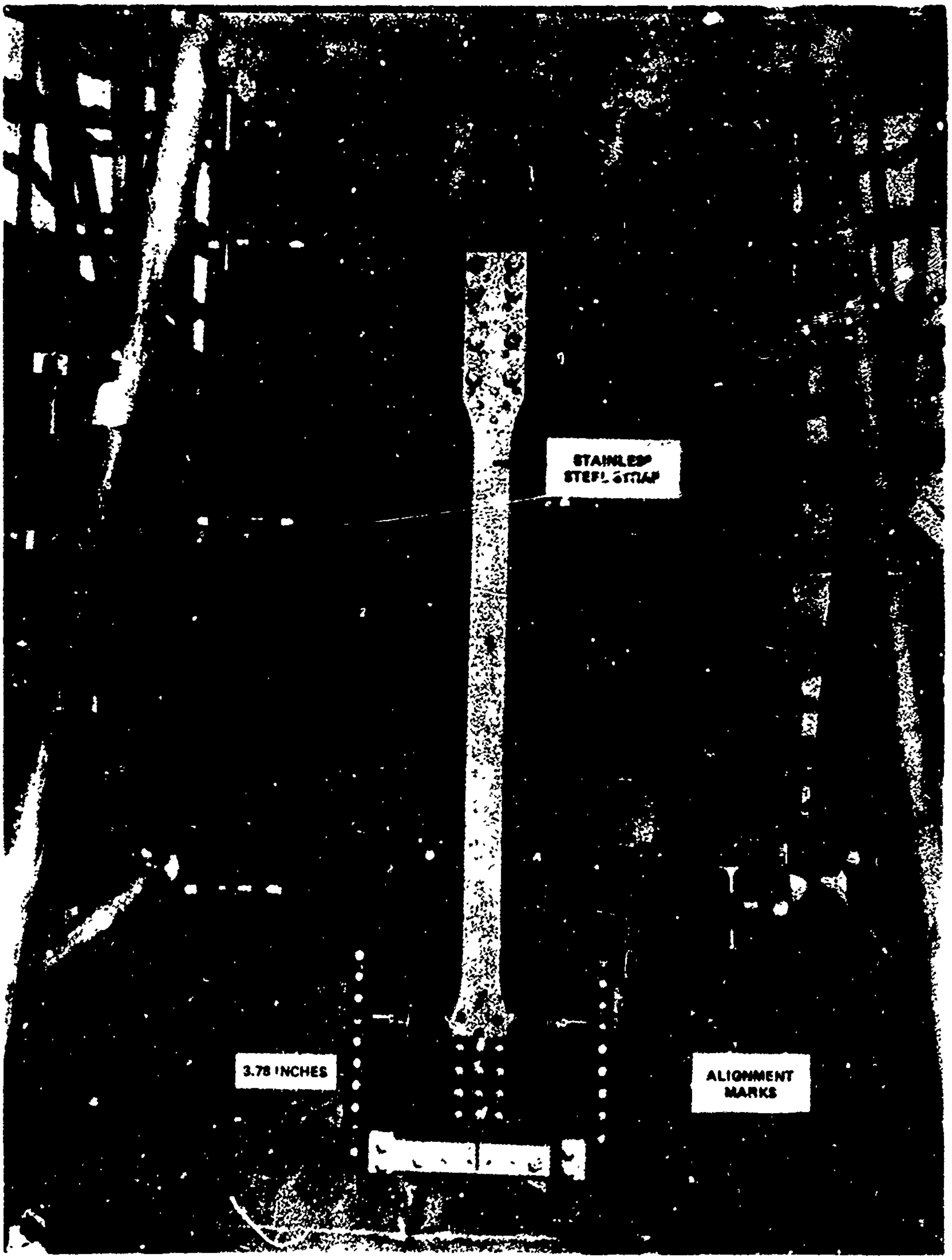


Figure 56. F7U-3 Load Attenuation Strap Showing Elongation After Test Ejection.

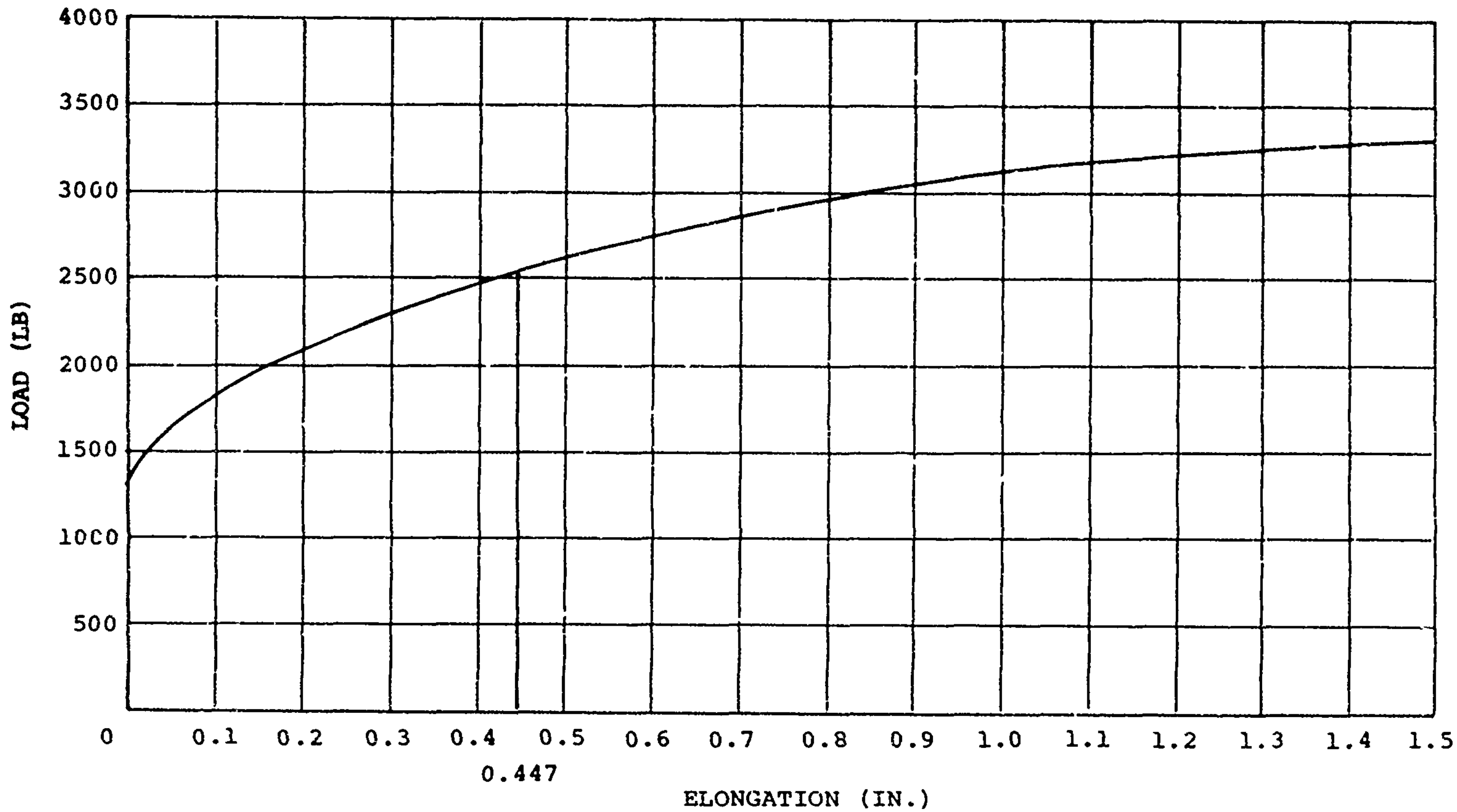
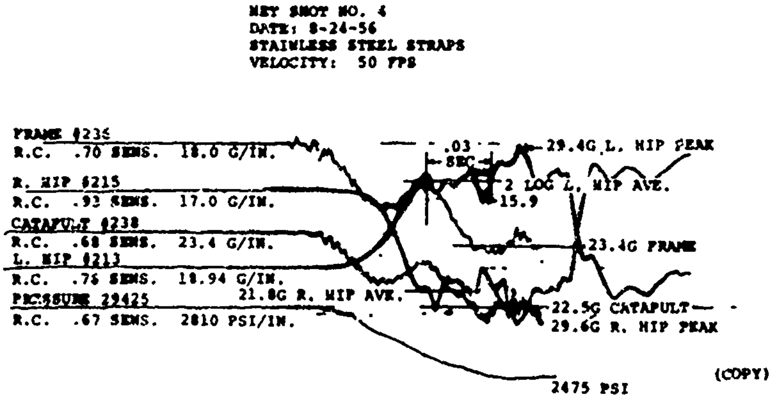
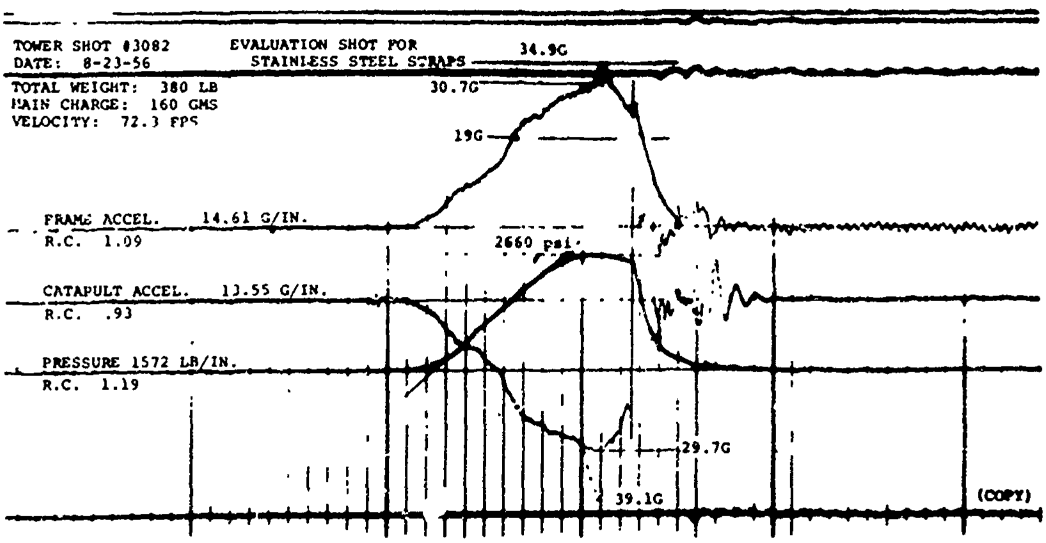


Figure 57. Typical Stress-Strain Curve of Strap Material Specimen.



a. HIGH G TEST USING STRAP TO DETERMINE REDUCTION OF FORCES IN b.



b. HIGH G TEST WITHOUT STRAP TO DETERMINE FORCES AND FOR COMPARISON WITH a.

Figure 58. Oscillograph Records of Strap Performance.

NET LOAD LIMITERS

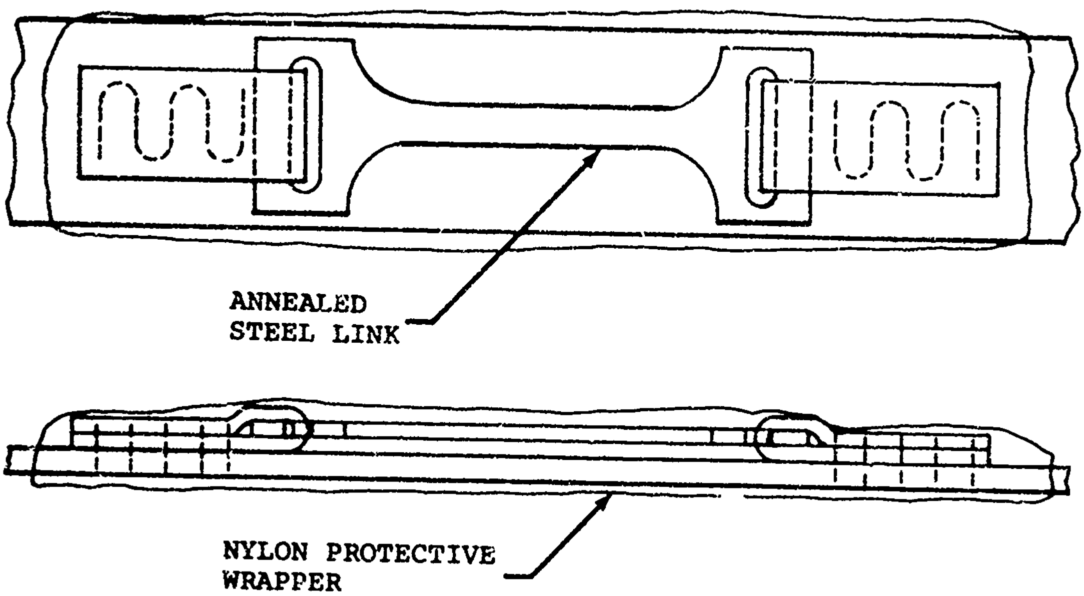


Figure 59. Tensile Strap Attached to Nylon or Dacron Webbing.

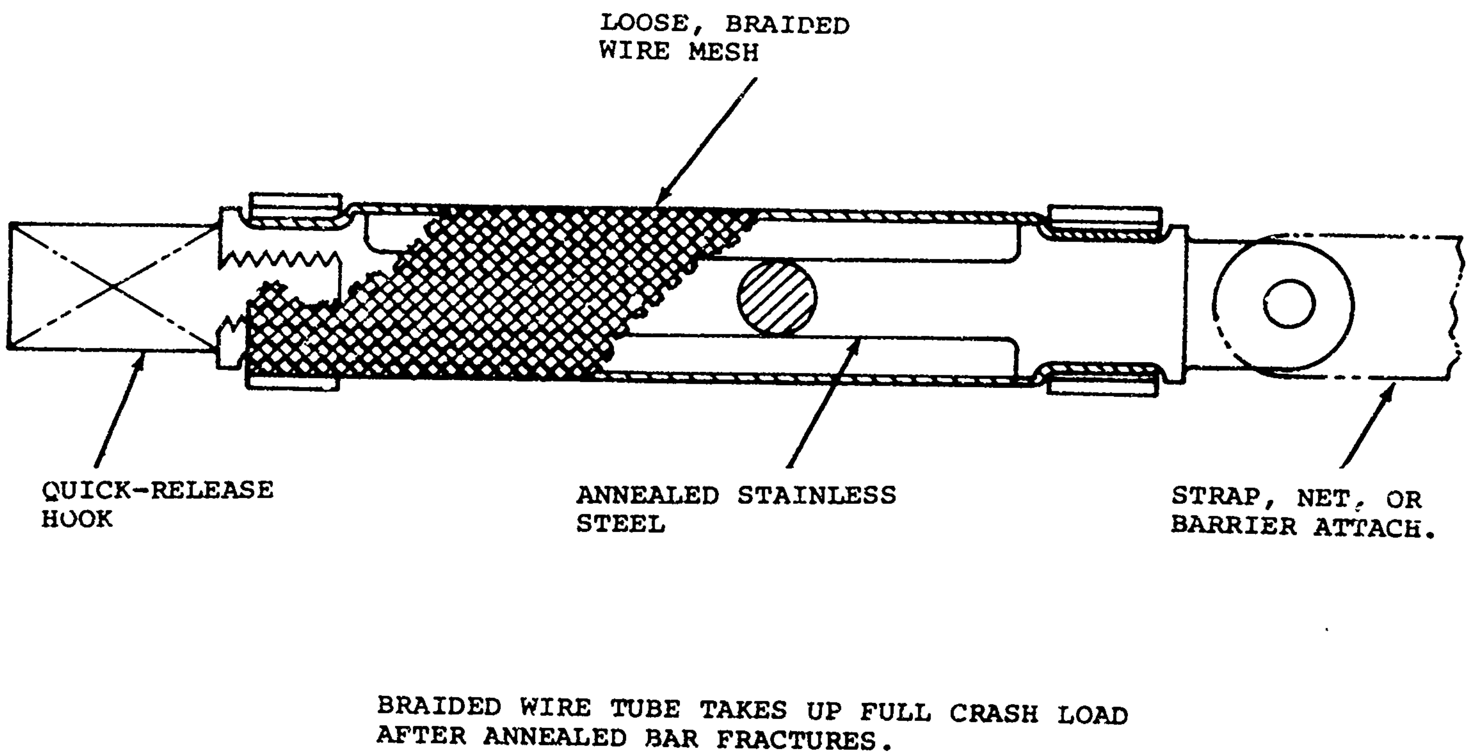


Figure 60. Load Limiter Using Tensile Bar With Braided Wire Outer Tube.

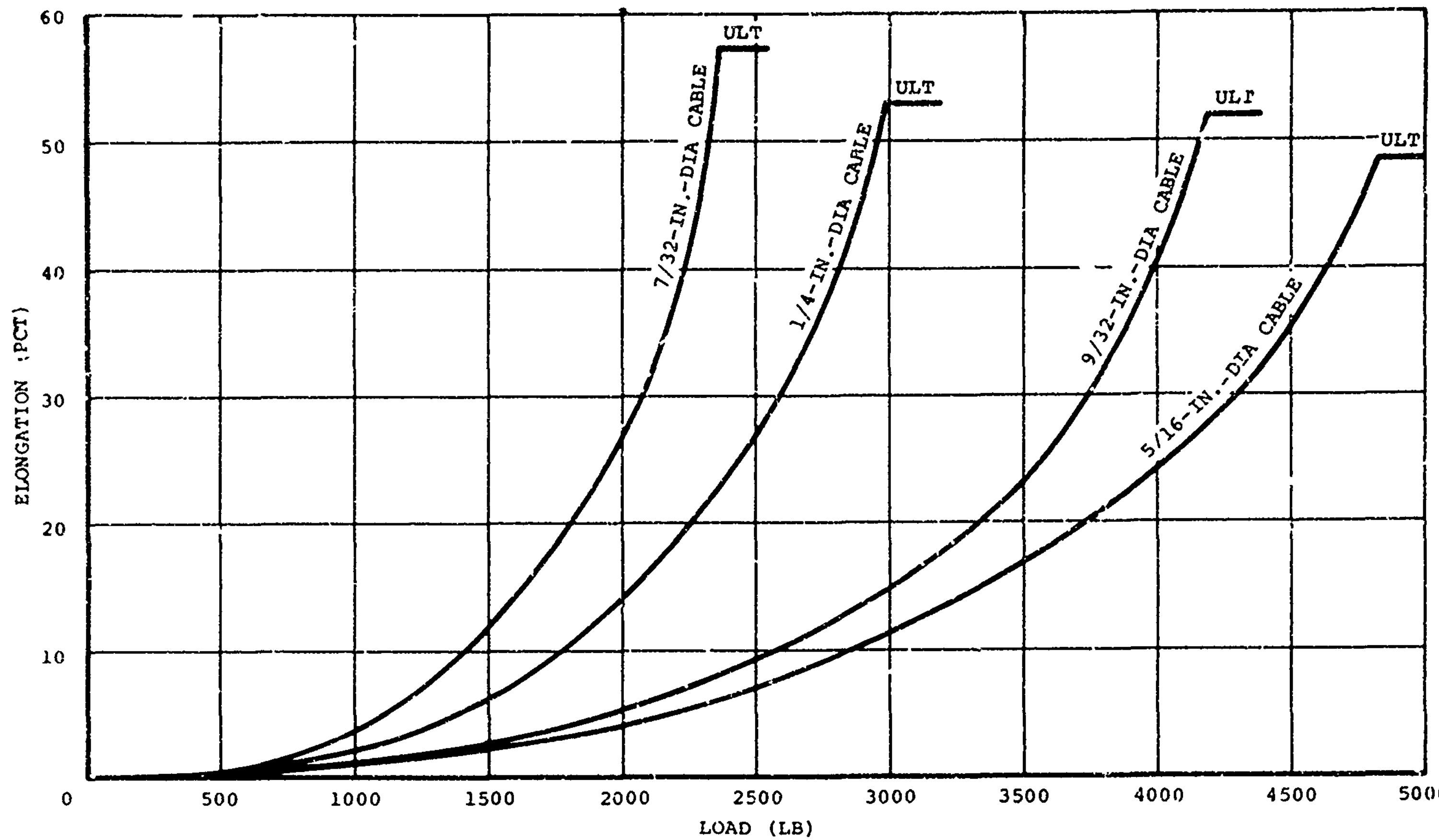
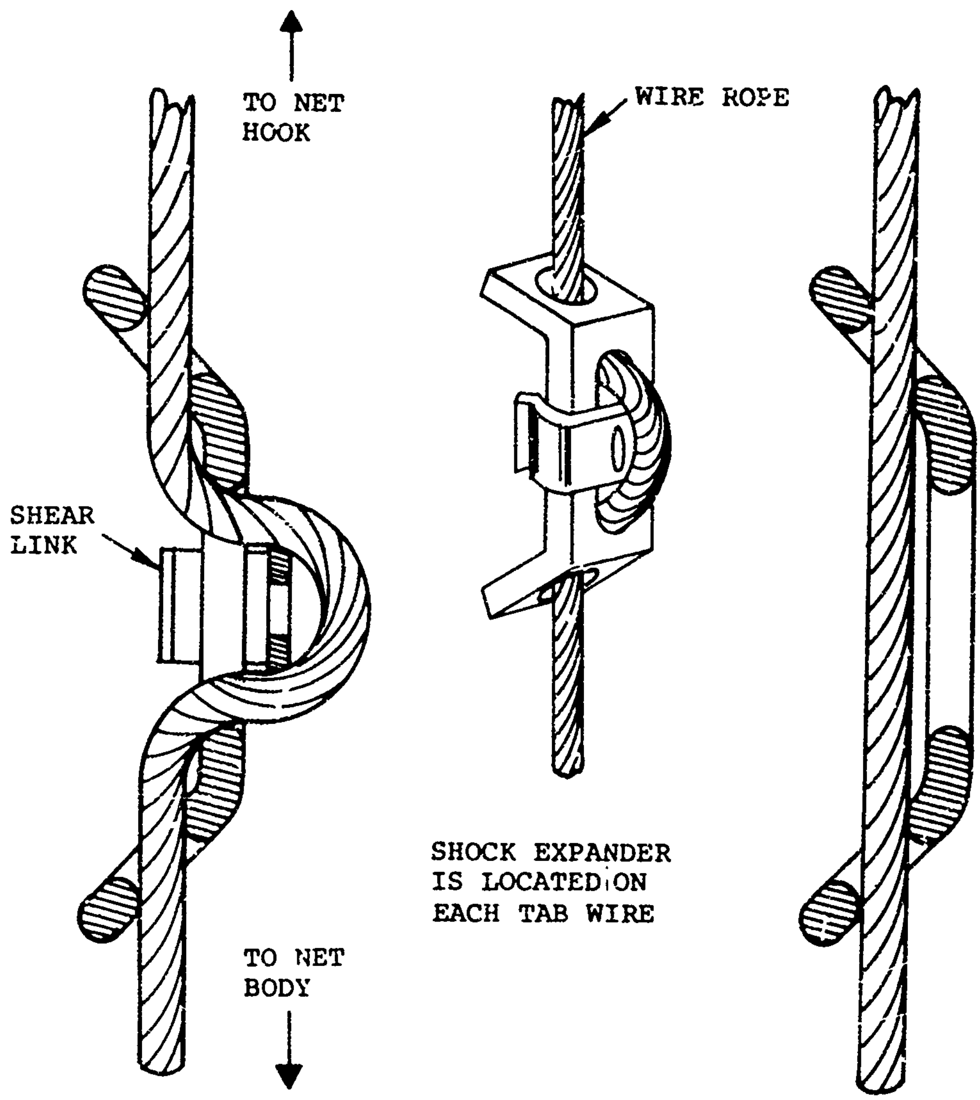


Figure 61. Stress-Strain Curves of Fully Annealed Stainless Steel Cables.



NORMAL POSITION OF SHOCK EXPANDER BEFORE LOAD OF 6,000 LB HAS BEEN APPLIED.

EXPANDER AFTER 6,500 LB SHOCK HAS BEEN APPLIED TO TAB NET AND SHEAR LINK IS BROKEN OUT. TAB WIRE EXPANDS 2 INCHES AND ASSUMES STRAIGHT LINE. TAB WIRE THEN HAS 9,800 LB MIN BREAKING STRENGTH.

Figure 62. Shock Expander for Strap and Net Application (Peck and Hale).

Compressed Solid Medium (Friction or Viscose Damper Concept)

The Menasco Manufacturing Company of Burbank, California, designers and manufacturers of landing gear shock struts, has also developed units for load attenuation in the form of liquid spring and solid medium devices.

A liquid spring device capable of a 4-inch stroke for a 1-to-2-millisecond duration has been fabricated and successfully tested for use in an explosive application. The unit consists basically of a cylinder, a piston, and a liquid (silicone) which is forced through a single orifice.

As a derivative of the liquid spring, a compressible solid medium (silicone polymer compound) to replace the liquid is in the development stage. At present, this unit appears to be too heavy for aircraft use.

At the present time, both units are used with rebound effects in which the rate of load is controlled. However, a Menasco representative has indicated that the rebound feature, currently being investigated, can be eliminated. A device of this nature would also require less cylinder wall and less costly manufacturing tolerances. Velocity of loading is also controllable by variation of orifice design.

The manufacturer believes that the silicone units would have a 5- to 10-year shelf life without maintenance, and that those involving the silicone polymer would have an infinite life and would require no service since sealing would not be a problem. Figure 63 shows a typical compressible solid medium shock strut, and Figures 64 and 65 are typical performance curves. Figure 66 illustrates a liquid spring concept as previously described. Either tension or compression applications may be designed, the latter being lighter in weight. Response curves for the compressed solid medium units are not available as yet.

Other manufacturers are evaluating porous metals, although no information is available about them at this time. Figure 67 shows an add-on load attenuator configuration which might be developed around this concept.

An alternate application of Menasco's design (Figure 68) is shown installed in and adapted to the general shape of the cargo tiedown rail, eliminating the weight of separate packaging.

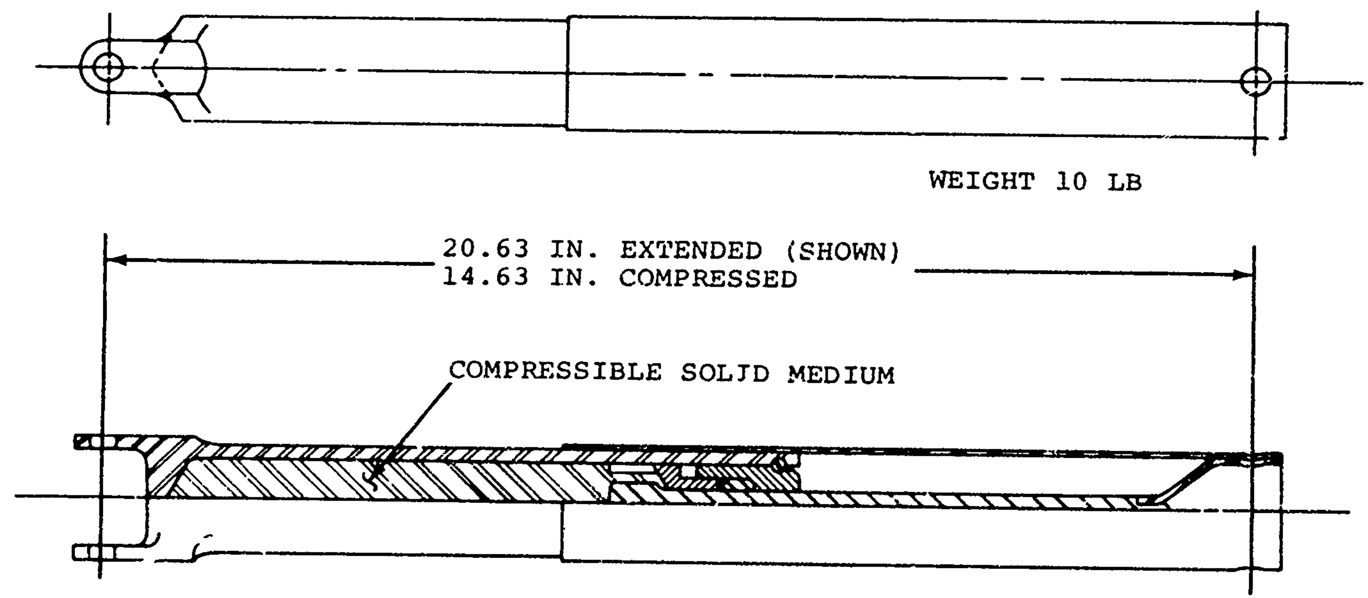


Figure 63. Compressible Solid Shock Absorber (Menasco).

NOTE: TEST RUN WITH PISTON AND CYLINDER CLEARANCE OF 0.002 IN. PER SIDE AND TWO 1/4-IN. HOLES THROUGH PISTON.

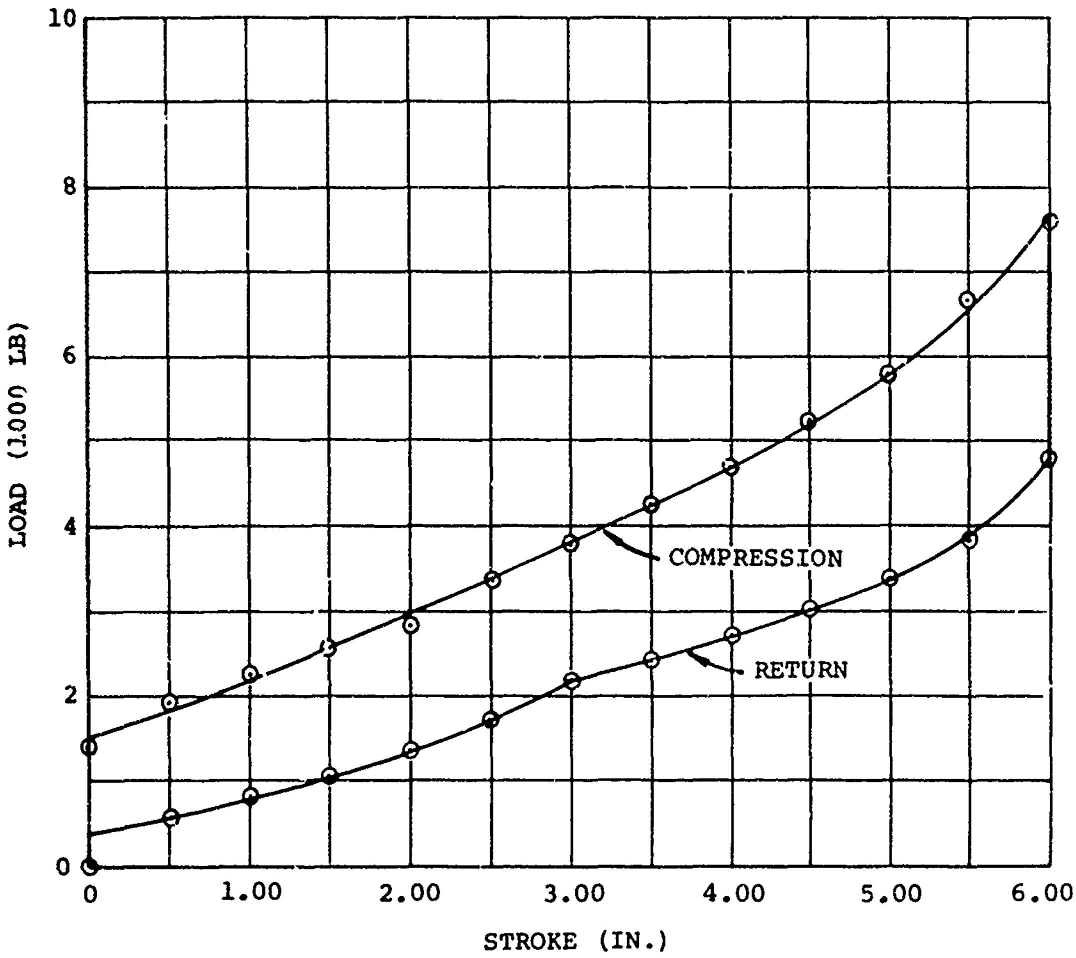


Figure 64. Static Load Versus Stroke for Shock Absorber (Menasco).

TEST CONDITIONS

AMBIENT TEMPERATURE
DROP WEIGHT IS 1135 LB

DROP HEIGHT (IN.)	CALCULATED IMPACT VELOCITY (MPH)
○ 12	5.47
△ 18.7	6.83
□ 30.0	8.65
⬡ 40.0	9.98

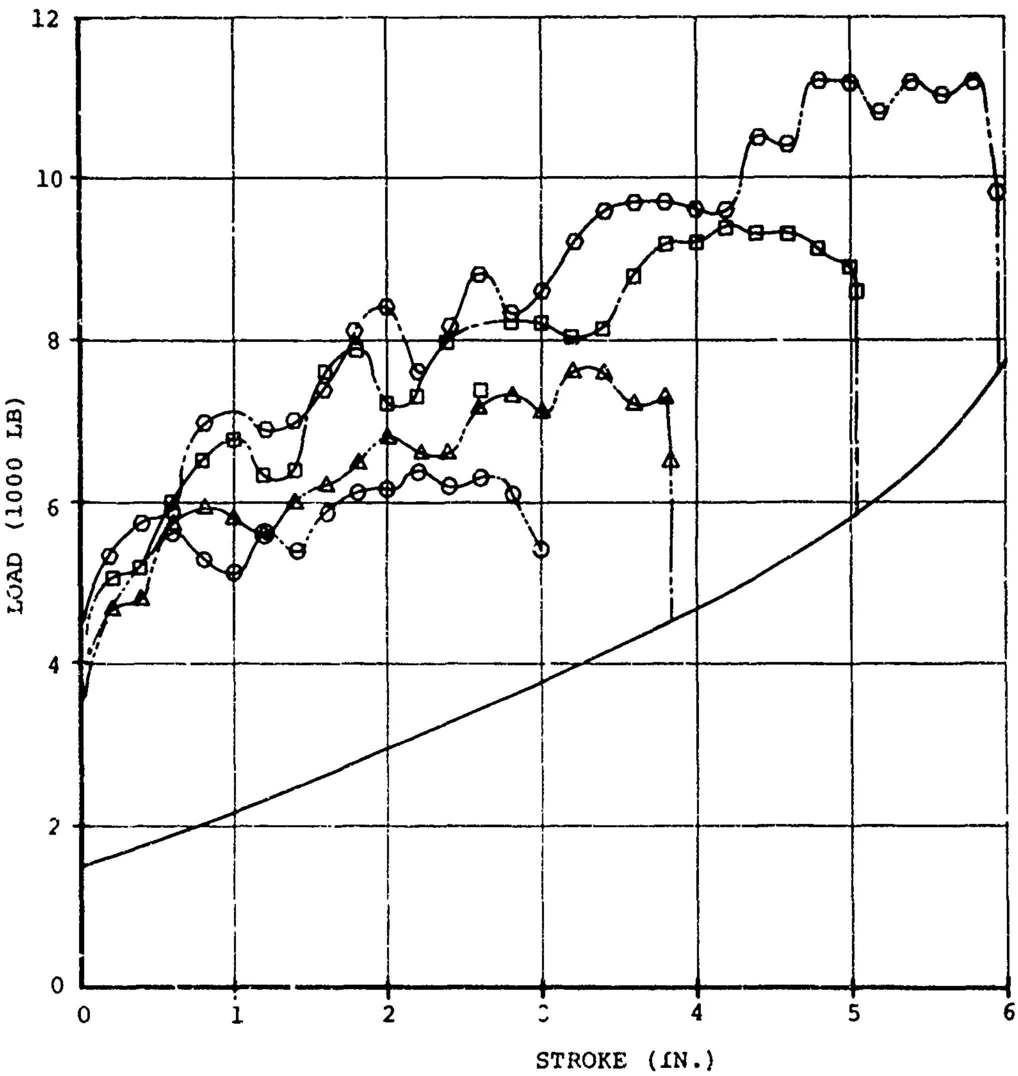
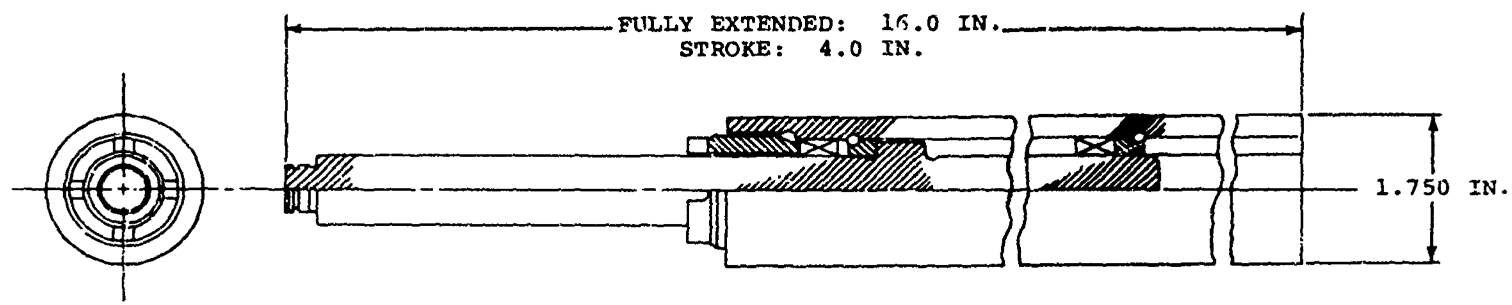


Figure 65. Load Versus Stroke per Shock Absorber (Menasco).



LIQUID SPRING
(1) WEIGHT: 5.5 LB
(2) INPUT FUNCTION PERFORMANCE:
340 IN./SEC VELOCITY WITH
RISE TIME OF 3.5 MILLISECONDS
(3) OUTPUT FUNCTION PERFORMANCE:
10G MAX WITH 300-LB LOAD

Figure 66. Liquid Spring Shock Mitigation Device (Menasco).

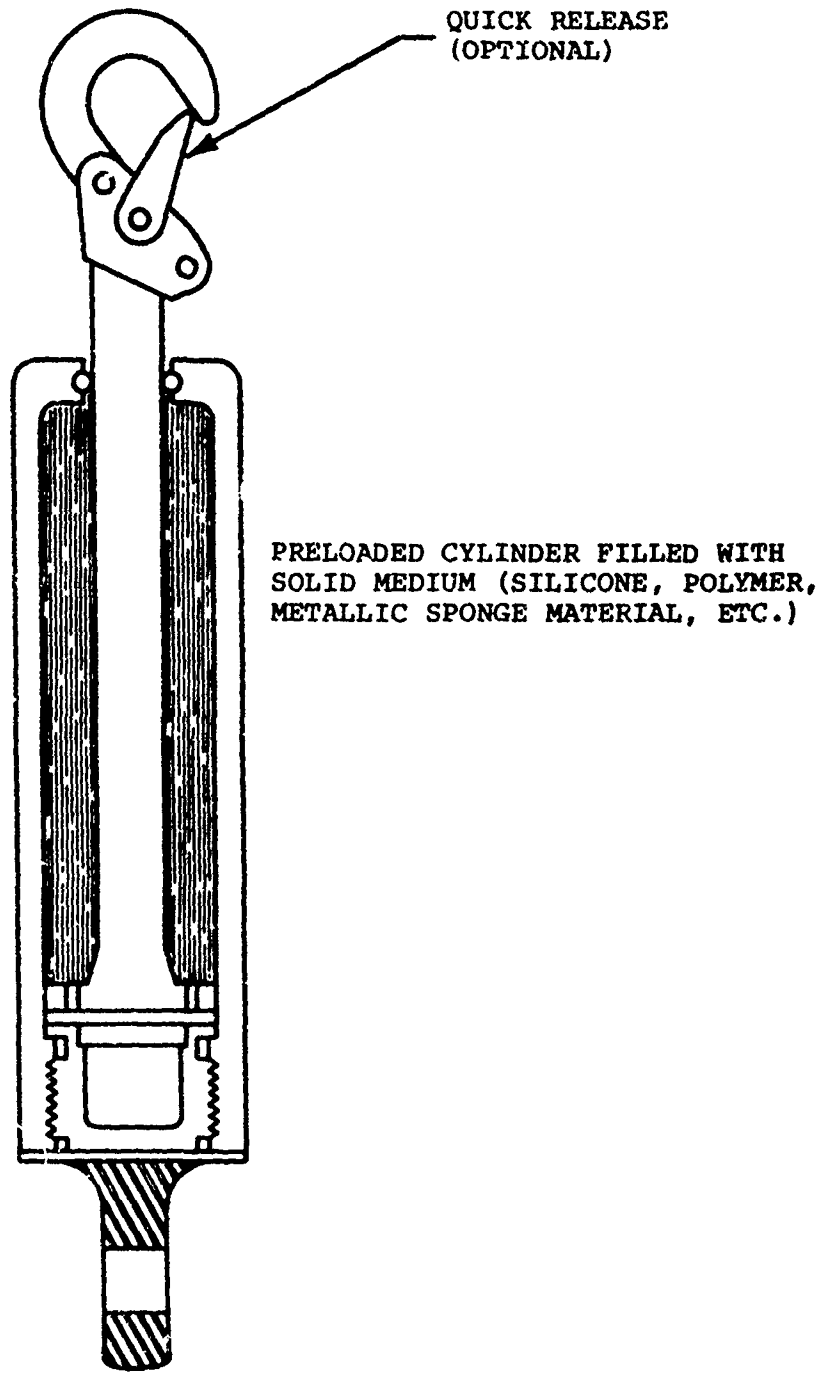


Figure 67. Load Limiter Concept Using Compression of Solid Medium (Menasco).

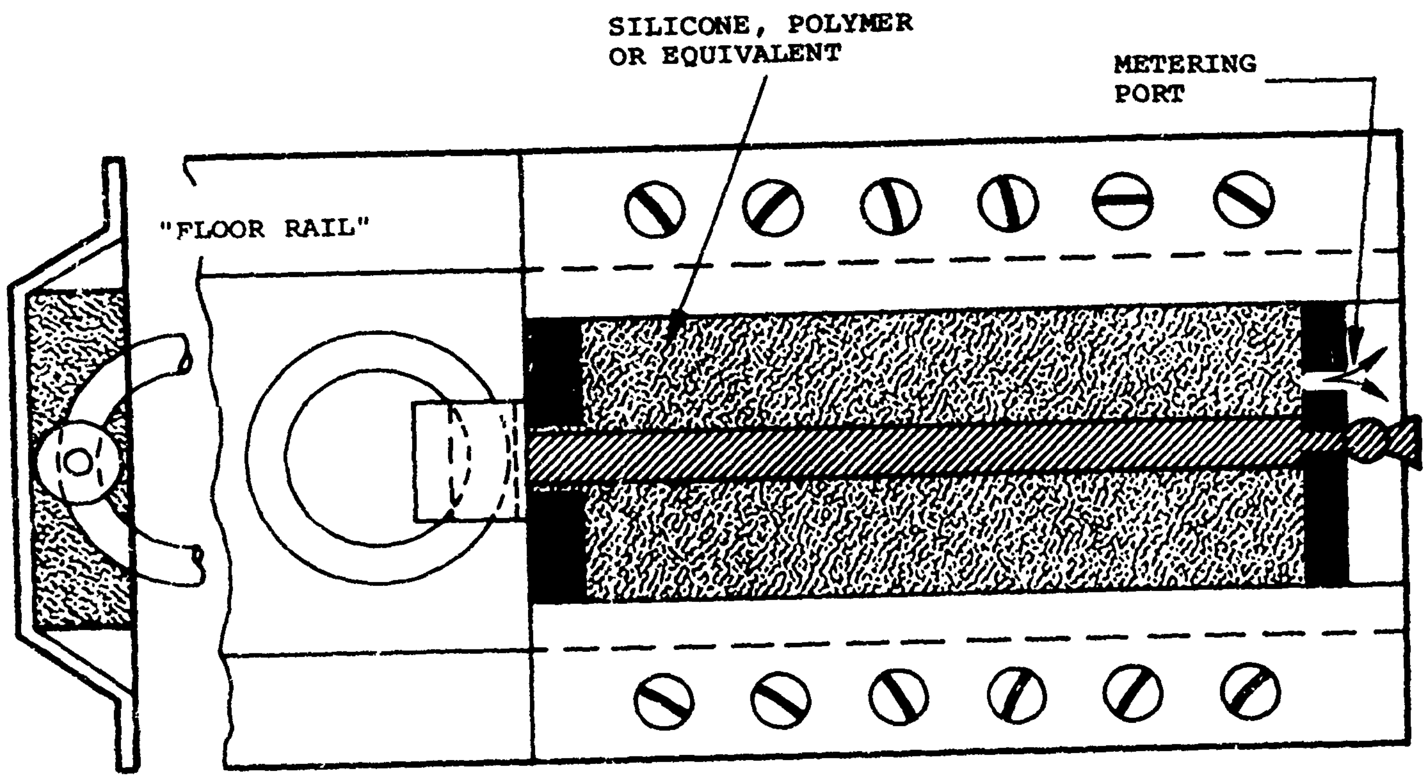


Figure 68. Compressed Solid Medium Energy Absorber, Alternate Design Concept.

Inflatables

NASA (Reference 32) has extensively investigated the use of inflatables for landing load attenuation purposes. Test results have indicated that constant load levels are difficult to maintain and would require a sophisticated pressure control unit within the inflatable bag. Work in the development and design of inflatables for cargo restraint is currently being done by the Arlitt Company of Dallas, and others.

NASA, in its investigation of inflatables for use on lunar vehicles, has compared them with material deformation and collapsible shell concepts. The overall evaluation rated them as good, with an energy absorption/system weight from 6,000 to 12,000 foot-pounds per pound. In addition, crash load attenuation is not as critical for airbag restraint use in the helicopter as it is in the space application. Their potential application is illustrated in the system concept definition of this report. It should be noted that the railroads and trucking industries are using inflatables as dunnage to reduce cargo shipping damage. (See Figures 69 and 70.) Figure 71 indicates the type of deceleration or load absorption characteristics capable from this type of device.

Barrier Nets

The barrier nets as presently used in commercial aircraft (References 36 and 37) are designed for a static 9g load factor rather than a dynamic g load factor and are primarily concerned with forward crash restraint. An improvement of these barriers to react to dynamic cargo loads may be realized by the integration of load attenuators into the net matrix for energy absorption. Almost any of the previously discussed devices could be adapted to net construction and/or installations, as illustrated in Concepts II and III in Section 5, CANDIDATE CARGO RESTRAINT SYSTEMS.

Automotive Crash Attenuation Development Trends

Of interest is the considerable amount of research being conducted on crash attenuation devices by the automobile manufacturers, both here and abroad. In this country, activity has been generated, in part, by recent legislation (Reference 38) passed in an attem- to curb the growing accident death and injury tolls, and . industry competition.

Current safety features include such ideas as:

1. Collapsible steering column (which approximately doubles the weight of a steering assembly) (Reference 11)

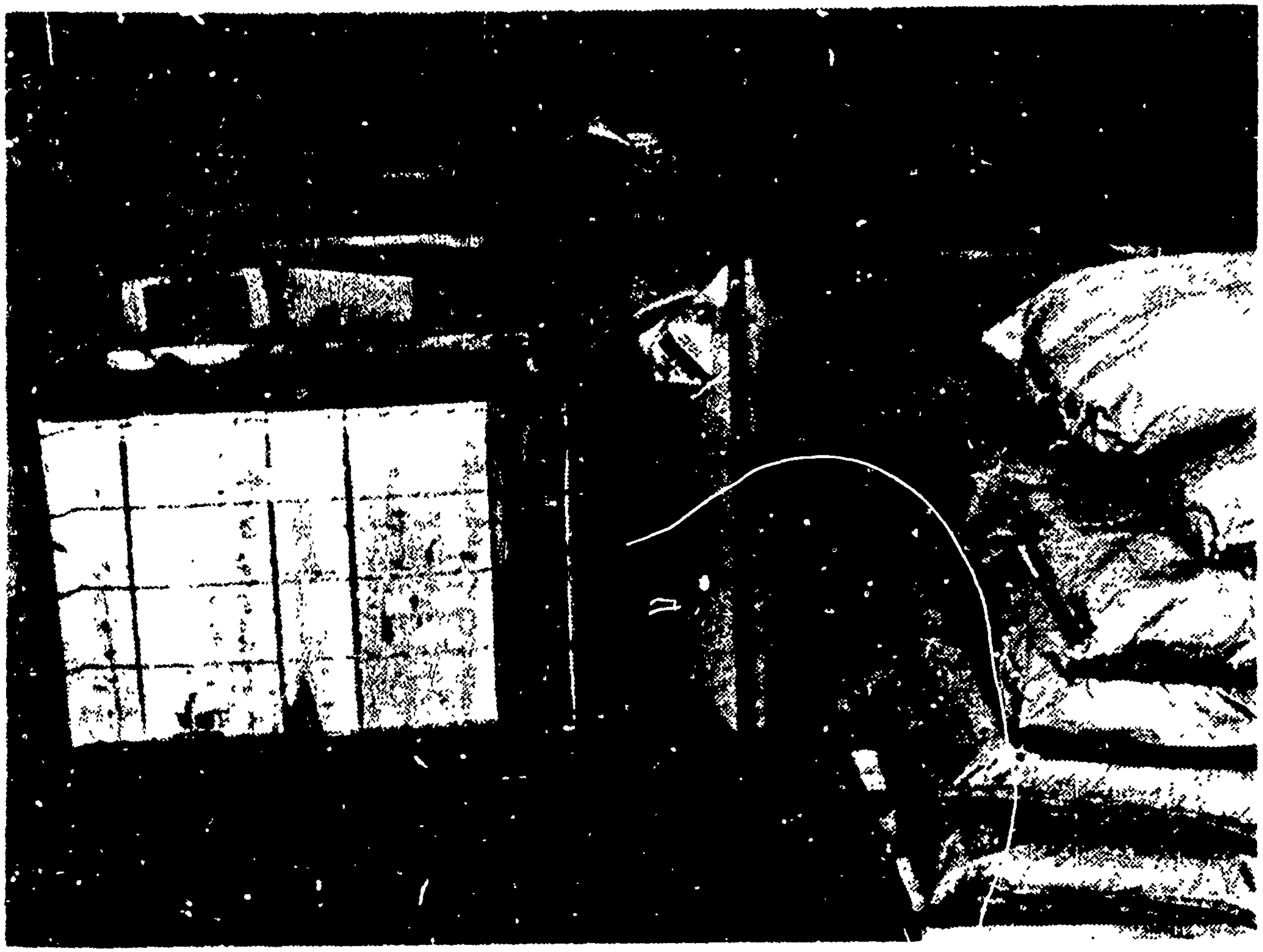


Figure 69. Disposable Inflatable Dunnage Bags to Prevent Cargo Shifting in Railroad Car.

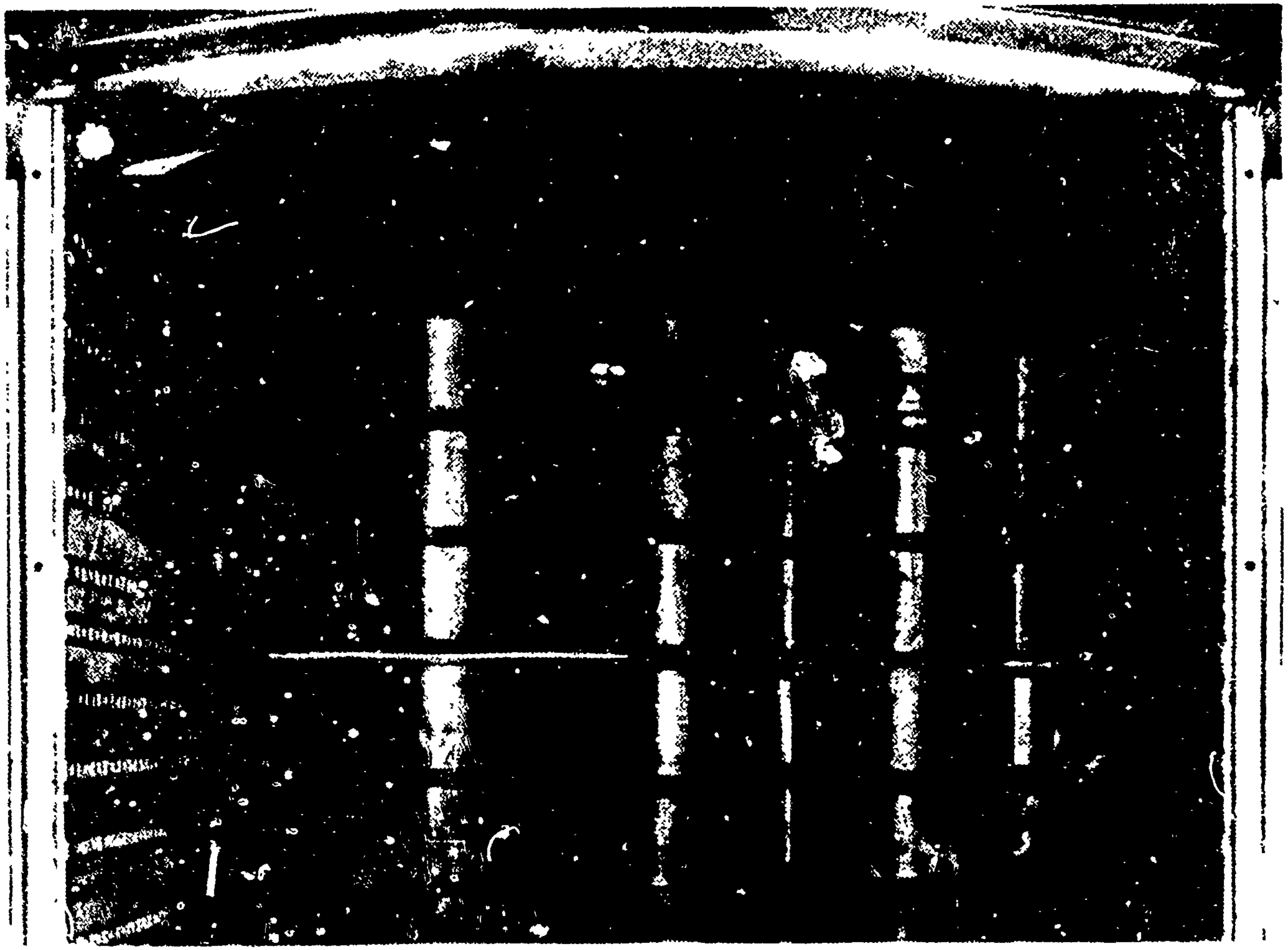


Figure 70. Nondisposable Inflatable Dunnage Bags Restraining 55-Gallon Drums in Trailer Truck.

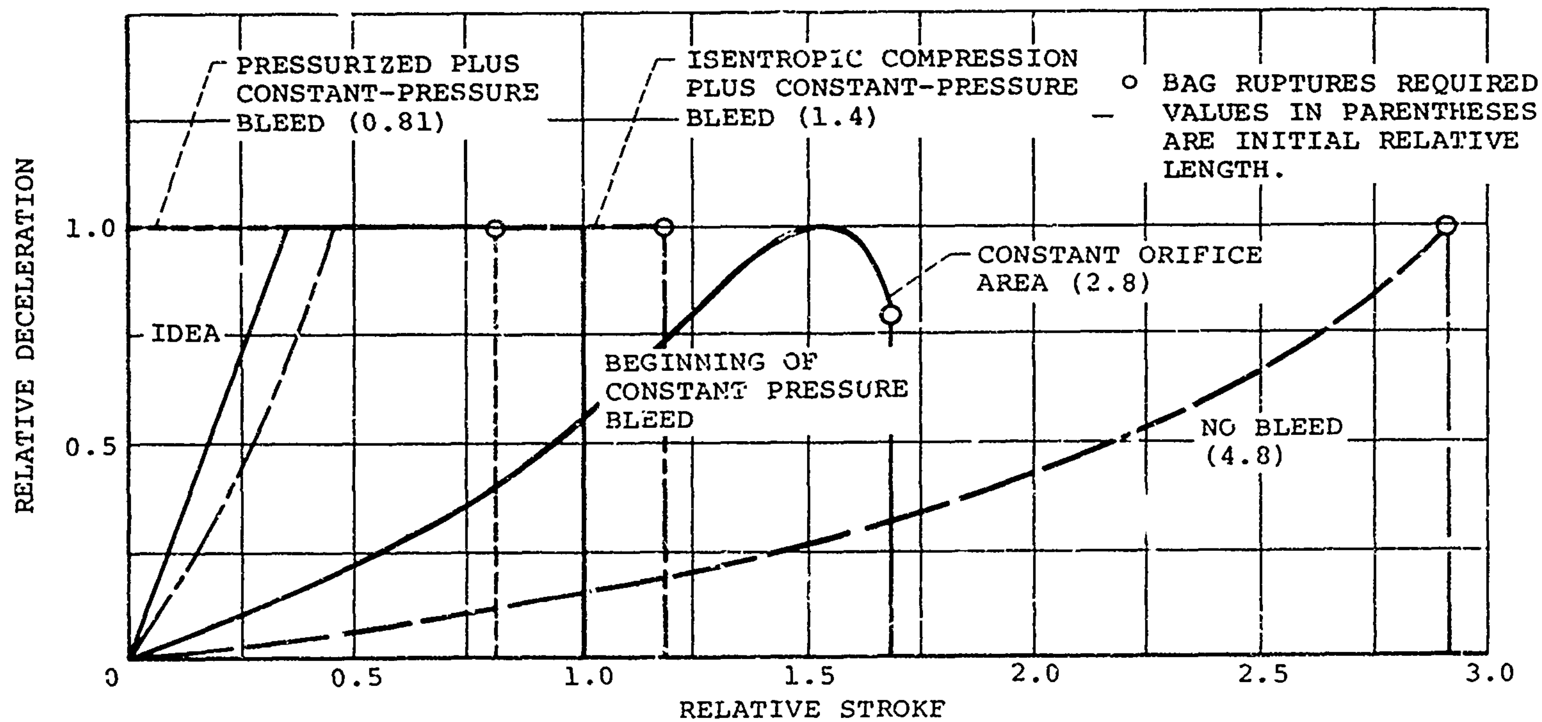


Figure 71. Deceleration Characteristics for Various Types of Gas Bags (NASA).

2. Air bag restraint system for driver and passengers (including a fail-safe accident sensing system) (Reference 12)
3. General Motor's side impact bars (Reference 13)
4. Encapsulating (armored type) seat development tests (Reference 14)
5. Controlled crush of sheet metal and frame parts (of common materials) (Reference 15)
6. A complete safety engineered automobile (Reference 16)

2.6 ACCIDENT SURVIVABILITY DATA

The large-scale movement and supply of military units by cargo transport helicopter airlift has created new problems in cargo handling and restraint. New safety hazards develop during tactical helicopter airlifts and must be weighed against the urgency of performing the mission.

The objective of cargo restraint, beyond controlling the movement of cargo during flight maneuvers, is to control the cargo during a survivable crash sequence and thus minimize hazards to personnel. There are occasions when this appears to be impossible, as in the case of large bulk items and the evacuation of Vietnamese people and their belongings, as shown in Figures 72 and 73.

In defining a new cargo restraint system to protect crew-passenger-cargo mixtures in helicopters, it is anticipated that ultimate crash safety will require cargo restraint in all directions. Since a total environment is involved, it appeared appropriate to observe the results being obtained with present systems. Likewise, the influence of factors unrelated to the cargo that could seriously influence the improvement in crash survivability were considered. These secondary factors may also be responsible for fatalities in an otherwise survivable crash.

The procedure followed for this investigation was:

1. Review available helicopter accident reports for cargo related factors:
   a. Mechanism of load breakaway and consequences
   b. Structural or other factors contributing to crash survivability
2. Review current safety and crash survivability literature.

Contacts were made with the following sources of accident statistical data, with results as noted. For the accident case review, the form shown in Figure 74 was used.

Figure 72. Loading Temporary Bridge Sections into CH-47 Helicopter in Vietnam.

Figure 73. CH-47 Airlift of Vietnamese Belongings.

ACCIDENT DATE: ________ AIRCRAFT SER. NO.____________ REPORT
USABAAR REPORT NO.:____________ TAB NO.____________ DATE:________

CARGO	CARGO BREAKAWAY	
	CARGO TIED DOWN? YES/NO (EXPLAIN)	
	RESTRAINT FAILURE	
	A/C STRUCT./TIEDOWN FAILURE	
	CARGO TYPES	
	CARGO/PERSONNEL LOCATION	
FATALITY	FATALITIES (NUMBER)	
	FATAL: CARGO RELATED	
	POTENTIAL FATALITY (CARGO)	
	NO. ON BOARD	
IMPACT DATA	A/C IMPACT VELOCITY	
	DIRECTION FWD,AFT,L,R / ANGLE, OTHER	
	A/C DAMAGE	
	GROUND DAMAGE	
	FUSELAGE COLLAPSE AROUND INHABITANTS?	
	PERCENTAGE OF A/C DAMAGE: FIRE	

ACCIDENT DESCRIPTION

Figure 74. Data Form for Review of Cargo-Related Survivable Helicopter Accidents.

Boeing Records - Out of 390 accident cases reviewed, 11 were directly related to cargo or equivalent loose objects on board. While cargo was often a prime suspected cause of injury or death, information in medical officers reports (MOR's) on such items as cargo tiedown methods, location, and types were often vague and more often unavailable. This was a serious handicap in obtaining a true picture of the effect of cargo breakaway. While some statistical records are programed for cargo related factors, information for the records was often not provided. This information, if available, would illustrate the contribution of cargo restraint to the incident and would help define the environmental problems which must be solved.

U.S. Army Board for Aviation Accident Research (USABAAR) and U.S. Naval Safety Center - The USABAAR and U.S. Naval Safety Center data retrieval systems were not capable of detailed isolation of situations. They did, however, offer to make their files available to Boeing for a study review. Due to the planned limited nature of this survey, data searches of areas requiring such treatment were not undertaken.

Canadian Forces Safety Center - The RCAF center indicated that the data requested could be retrieved; however, no data was obtained during the report period.

Norton Air Force Base Safety Center - A data search and electronic printout was promised by the Air Force and was to be made available for review by Boeing representatives. However, results of this search did not become available during the report period.

Accident Study Results

Results of the accident investigation review may be summarized as follows:

Cargo as a primary causal factor

Cargo or loose equipment which can be considered as cargo has been identified as a direct cause of, or is thought to have contributed to, accidents which otherwise would have been survivable.

Restraint direction

The review indicates that helicopter crashes have occurred with impact from every conceivable attitude, including being inverted, with the most frequent mode of impact occurring in the aircraft longitudinal direction.

Combat Emergency

Cargo loading under combat emergency conditions and conditions in which insufficient tiedown had been made were found to be contributing factors to fatalities.

Other Environmental Factors

Examination of photographs and written descriptions of the CH-47 accidents covered generally indicate the maintenance of the integrity of the cabin structure. It is therefore believed that the collapse of the inhabited area (cockpit not included) has not in itself been identified as contributing to fatalities.

Likewise, pylon-mounted equipment and/or engine nacelles did not generally intrude into the habitable cabin area. Fatalities caused by other than cargo factors were: (1) passengers being unrestrained, (2) post-crash fires, and (3) the secondary effects of impact. These points are illustrated by the accident summaries in Appendix II.

Several factors beyond the scope of an improved cargo restraint system are apparent from the accident survey. Moreover, it appears that increases in survivability resulting from new systems could be reduced by other major events which occur as part of the overall crash sequence. These events, which in themselves are both causal and contributing factors, are:

1. Lack of personnel restraint
2. Inaccessible or restricted egress
3. Post-crash fire
4. Some nonhardware factors, which include:
    a. Combat urgency
    b. Lack of flight- and crash-safety awareness
    c. Apathy toward use of available tiedown equipment

These findings are supported by another Boeing in-house investigation of rollover accidents (Reference 39) and reports of the Light Observation Helicopter (LOH) crash survivability (References 40, 18, and 41). The LOH, for example, which was designed considering crash impulse technology, has established crash pulse attenuation by means of the following:

1. Landing skid plastic deformation
2. Crushable keel beam and fuselage subfloor structure shielding the fuel tanks and reducing post-crash fires
3. Integral deformable crew seats
4. Fuselage (rollover) truss preventing major structural collapse from overhead transmissions, etc.

The CH-47 Chinook, although designed in 1958, has similar good crash survivability potential since its monocoque structure has shown a tendency to maintain its cabin shape. Nevertheless, further improvements are possible, such as:

1. Deformable protection for the fuel tanks
2. Additional load attenuation at the cargo floor
3. Use of a high-energy landing gear
4. Load attenuating crew and passenger seats
5. Additional emergency egress provisions

Combined with an integral restraint system, improvements of this type will aid in the broad attack on the crash survival problem.

The accident and cargo restraint reviews suggest that implementation of the following recommendations should produce immediate benefits:

1. Undertake measures in the field to overcome reluctance in the use of current equipment by creating an awareness of crash-safety requirements.
2. Institute procedures for applying restraint to small items, presently ignored, which are potential missiles under crash conditions.
3. Provide more details in accident analysis and investigation to provide the proper understanding of the restraint problem. Additional information may point the way to other areas of immediate improvement.

These items, plus improvements forthcoming from the industry-wide study of post-crash fires, will undoubtedly provide the means of obtaining significant success in crash survivability. In the development of the projected integral helicopter cargo restraint system, safety criteria listed in Appendix II will be applied.

3. DESIGN CRITERIA

There are two basic types of cargo missions: (1) combat and (2) normal air transport operations. The inherent problem associated with combat operations is the limited time available to correctly restrain cargo to protect the crew against the environment due to an improbable crash. In addition, existing restraint techniques are too detailed to be used in a combat environment (see Figure 75 and Reference 4), and there are no effective means of restraining unconventional loads such as bags of rice. Because of the helicopter's limited storage space, cargo nets and other special equipment are seldom carried with the aircraft.

As part of the trade-off methodology for systems evaluation, the primary design objective will be an integral helicopter restraint system adaptable to both cargo missions. As an alternate, consideration should be given to devising a combat cargo restraint system that will envelop a less severe crash criteria than would be appropriate to normal air transported cargo. The development of a dual restraint system is conceivable where the combat cargo restraint system is an integral part of the normal air transported cargo restraint system.

3.1 DESIGN OBJECTIVES

Design considerations pertinent to an integral helicopter restraint system are:

1. A permanently installed, integral component of the airframe.
2. Minimum dependence on lashing or latching operations by loading crews.
3. Rapid and simple rigging and derigging of cargo; suitable and adaptable to the widest variety of cargo.
4. Emphasis on minimum component weights with sufficient sturdiness to withstand abuses inherent in the cargo handling environment.
5. Capable of continued cargo retention in the event that airframe, floor, and restraint components suffer relatively severe distortion.
6. Redundancy based on the premise that at least a portion of the system will be compromised by nonuniform load application and by structural disintegration.
7. System concept suitable for retrofitting into current aircraft as well as being applicable to new helicopter design.

Figure 75. Tiedown Ratios and Angles.

8. Personnel survivability
9. Personnel safety

3.2 CARGO CATEGORY

Categorizing Army cargo is necessary because of the large variety of packages carried in Army aircraft. This was accomplished in Reference 1 and is utilized for this study.

Class A Cargo

Loose items such as food, packages and ammunition boxes which are stacked together and require cargo nets as a restraint medium. Also, prepalletized cargo.

Class B Cargo

Homogeneous cargo such as vehicles and fuel barrels which are restrained by strap type devices.

3.3 DESIGN PULSE-DURATION ENVELOPES

The Design Guide (Reference 1) recommends that Army cargo be restrained to the crash-pulse duration criteria outlined in Table VII.

As a contract design objective, USAAVLABS has designated crash-pulse duration criteria pertinent to the 95th percentile of crash survivability (representing a longitudinal impact velocity of 60 fps). These values are shown in Table VII in parentheses.

It is recognized that the system weight required to fully restrain cargo at maximum payload and 95th percentile levels will be high; therefore, a slight reduction in the percentile levels is suggested. The Design Guide (Reference 1) recommends, with pertinent reasons, the use of impact data pertaining to the 90th and 80th percentile levels and longitudinal impact velocities of 51 and 44 fps respectively (see Table VII). This viewpoint is obtained from statistical estimates and experimental test data. The Design Guide also specifies a need for dynamic restraint in the forward and lateral directions for Class A cargo, but only in the forward direction for Class B cargo.

The reduced pulse-duration envelope criteria as recommended in the Design Guide will be utilized for this study along with the 95th percentile value for vertical impact. Also, it will be assumed that the g levels for Class B cargo and Class A cargo are of the same value, with the 90th percentile value prevailing for the longitudinal direction. This is based on the information that, in actual practice, passengers are carried with all

TABLE VII. CRASH-PULSE DURATION CRITERIA					
Impact Direction	Cargo Class	Peak[3] (g)	Avg[3] (g)	Pulse Duration (sec)	Percentile of Survivable Crashes
Longitudinal[1]	A	20	10	0.158	90
	B	13.5	6.5	0.210	80
(4)	-	(27)	(13.5)	(0.138)	(95)
Lateral[4]	A&B[2]	10	5	0.130	90
	-	(16)	(8)	(0.097)	(95)
Vertical[4]	A&B	(48)	(24)	(0.061)	(95)

NOTES:

1. Longitudinal replaces forward direction given in the design guide.
2. Category B added.
3. G loads are referred to cargo cabin area only (Reference 2).
4. Reference 1 general passenger compartment design recommendations, 95th percentile level, rotary-wing and light fixed-wing aircraft. Also furnished by USAAVLABS as crash-pulse duration envelope objective.

types of cargo without restriction. This information was derived from the review of RVN cargo security (see Section 2.1, SECURING INTERNAL CARGO LOADS). It appears more realistic for this study, but is contrary to Reference 1, which states:

> "It is assumed in this handbook that Class A cargo will sometimes be carried along with troops while Class B cargo will not. The above assumptions are based on the reliable knowledge that personnel are commonly transported together with Class A cargo (personal belongings, rifles, ammunition, foodstuffs) while they are seldom transported with Class B cargo because of the apparent dangers of such an arrangement."

3.4 DESIGN CARGO LOAD-DEFLECTION REQUIREMENTS

Pertinent to the crash design-duration envelope given in Table VII, the corresponding envelope of cargo deflection for restraint devices with load attenuators is depicted in Figures 76, 77, and 78. This data omits the tiedown restraint characteristics and uses only the load attenuator response to survivable crash conditions. With elastic tiedown restraints, the cargo deflection as shown on the curves will be augmented by an amount depending primarily on webbing characteristics, restraint tiedown length, g level design, dynamic response, and system friction. In order to utilize this data effectively, the restraint system should be influenced by the following:

1. Consider as a design guide the restraint characteristics of Dacron material or metal cable with the aim of a low-elastic restraint device (Reference 21).
2. Use the lowest design g level corresponding to practical cargo stroke.

The vertical up restraint will be measured in terms of a 5g static load factor (classes A and B) which is attributed to cargo rebound from a vertical down crash (see Reference 1). The vertical down restraint will be based on floor characteristics which are associated with the 95th percentile of survivability. Selection of an optimum cargo restraint deflection and its corresponding g level for the impact directions is accomplished in the following sections.

3.5 CARGO STROKE DETERMINATION

Energy absorber stroke or load stopping distance must be compatible with aircraft cabin, cargo dimensions, and location of personnel. The stroke must be a practical maximum and permit use of the lowest design g level for the restraint system. For the CH-47 aircraft, a cargo-to-aircraft clearance envelope has been established to optimize the restraint load-stroke combination for the aircraft lateral and longitudinal directions which are shown in Tables VIII and IX. The loads were located within the range of the CH-47C helicopter cg at 33,000 pounds gross weight. These clearances were obtained by determining the distance between the cargo and (1) airframe, (2) troop seats, (3) seated troops, and (4) stowed seats as shown in Figure 79.

The lateral stroke distance between internally carried vehicles and the aircraft structure available for load deflection varies from 11 to 15 inches (see Table VIII). An exception to this is the M107, 1-1/2-ton water trailer, with a possible stroke distance of only 6 inches to the floor frame intersection. The longitudinal clearances for load deflection are less critical, as shown in Table IX.

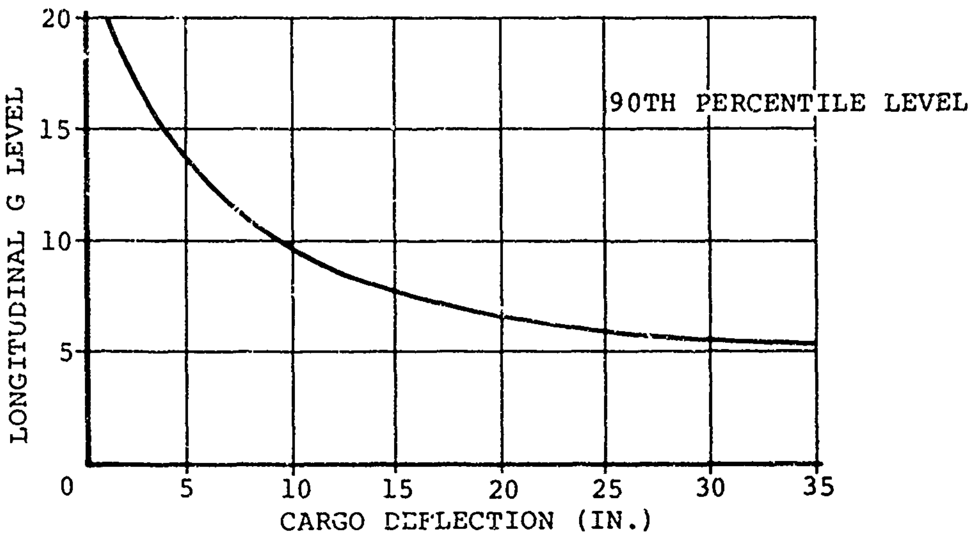


Figure 76. Longitudinal Load Deflection Requirements for Class A Cargo.

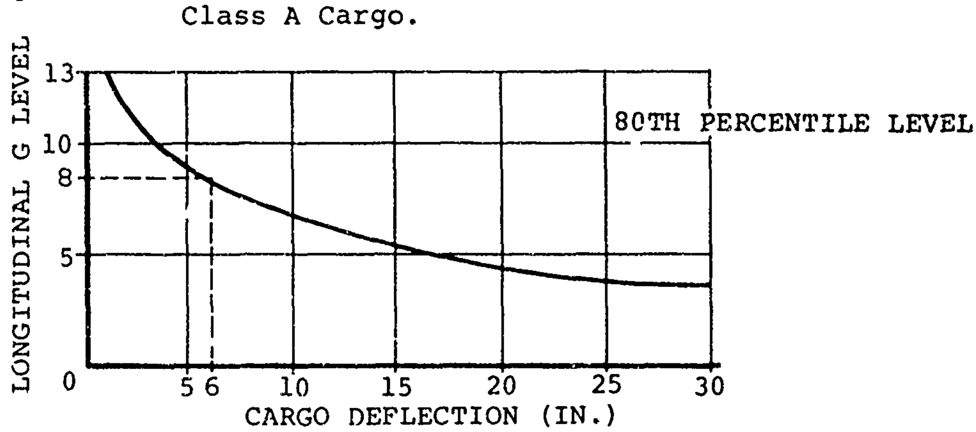


Figure 77. Longitudinal Load Deflection Requirements for Class B Cargo.

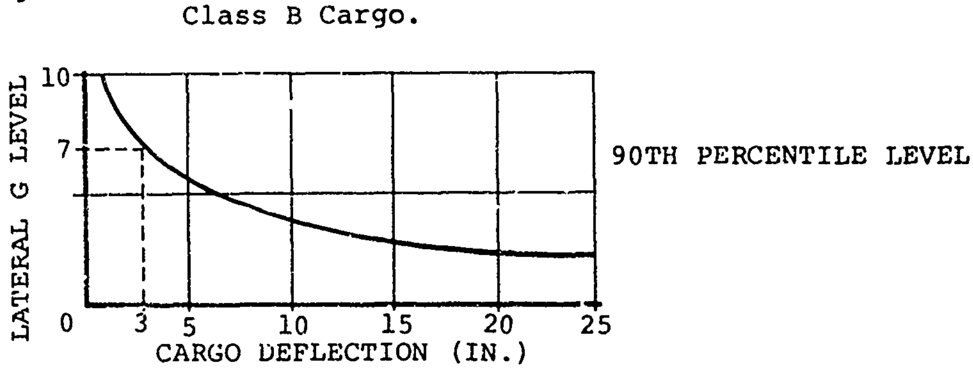


Figure 78. Lateral Load-Deflection Requirements for Class A Cargo.

TABLE VIII. CH-47 AIRFRAME LATERAL INTERFACE DIMENSIONS IN INCHES FOR TROOPS, TROOP SEATS, AND INTERNAL CARGO

Column No.	①	②	③	④	⑤	⑥	⑦
	Cargo Load Width (in.)	Location of Troop Seat Face (BL)	Location of Knees of Seat Occupant (BL)	Inter-section of Floor and Side Frame (BL)	Clearance or Interference between Cargo Load and Troop Seats	Clearance or Interference with Seated Troopers	Maximum Clearance to Airframe Structures
Internal Cargo Load	-	-	-	-	② - ① / ②	③ - ① / ②	④ - ① / ②
M151	64	24.95	18.95	47.00	- 7.05	-13.05	15.00
M100	57	24.95	18.95	47.00	- 3.55	-16.55	18.50
M416	62	24.95	18.95	47.00	- 6.05	-12.05	16.00
M170	61	24.95	18.95	47.00	- 5.55	-11.10	16.05
M-37	74	24.95	18.95	47.00	-12.05	-18.05	10.00
M107	82	24.95	18.95	47.00	-16.05	-22.05	6.00
M38 A/C	68	24.95	18.95	47.00	- 9.05	-15.05	13.00
M151	72	24.95	18.95	47.00	-11.05	-17.05	11.00
Sealdrum	72	24.95	18.95	47.00	-11.05	-17.05	11.00
Pallet	44	24.95	18.95	47.00	+ 2.95	- 3.05	25.00
55-Gallon Drums (2)	44	24.95	18.95	47.00	+ 2.95	- 3.05	25.00

NOTE: Negative value indicates interference with troop seats or occupant's knee.

TABLE IX. CH-47 AIRFRAME LONGITUDINAL INTERFACE DIMENSIONS IN INCHES FOR TROOPS, TROOP SEATS, AND INTERNAL CARGO

Column No.	1	2	3	4
Cargo Load	Forward Dimension to Nearest Seat	Forward Dimension to Struct at Sta 120	Aft Dimension to Nearest Seat	Aft Dimension to Struct at Sta 486
M151 1/4-Ton Truck	9	130	18	105
M100 1/4-Ton Trailer and M151 1/4-Ton Truck	12	56	14	80
M151 1/4-Ton Truck and	14	74	14	*
1 Wooden Pallet, 40 x 48 in.	14	*	16	50
M101 3/4-Ton Trailer and	8	16[illegible]	16	53
M107 1-1/2-Ton Water Trailer	9	140	23	67
M107 1-1/2-Ton Water Trailer and	9	80	24	*
1 Pallet, 40 x 48 in.	14	*	15	42
M107 1-1/2-Ton Water Trailer and	9	80	24	*
(4) 55-Gal Drums	20	*	20	47
(12) 55-Gal Drums (3 Groups of 4 Each)	8	76	8	44
M37 3/4-Ton Truck	22	103	14	80
3 Pallets (Ammo)	15	75	14	40

NOTES:

1. *Stroke controlled by second load.
2. Columns 1 and 3 indicate maximum available stroke is based on idealized (single) seating.
3. Columns 2 and 4 indicate maximum available stroke with stowed seats.
4. See Section 7 for vehicle and cargo tiedowns, including seating positions possible using single troop seats.
5. Most critical aircraft cg location used.

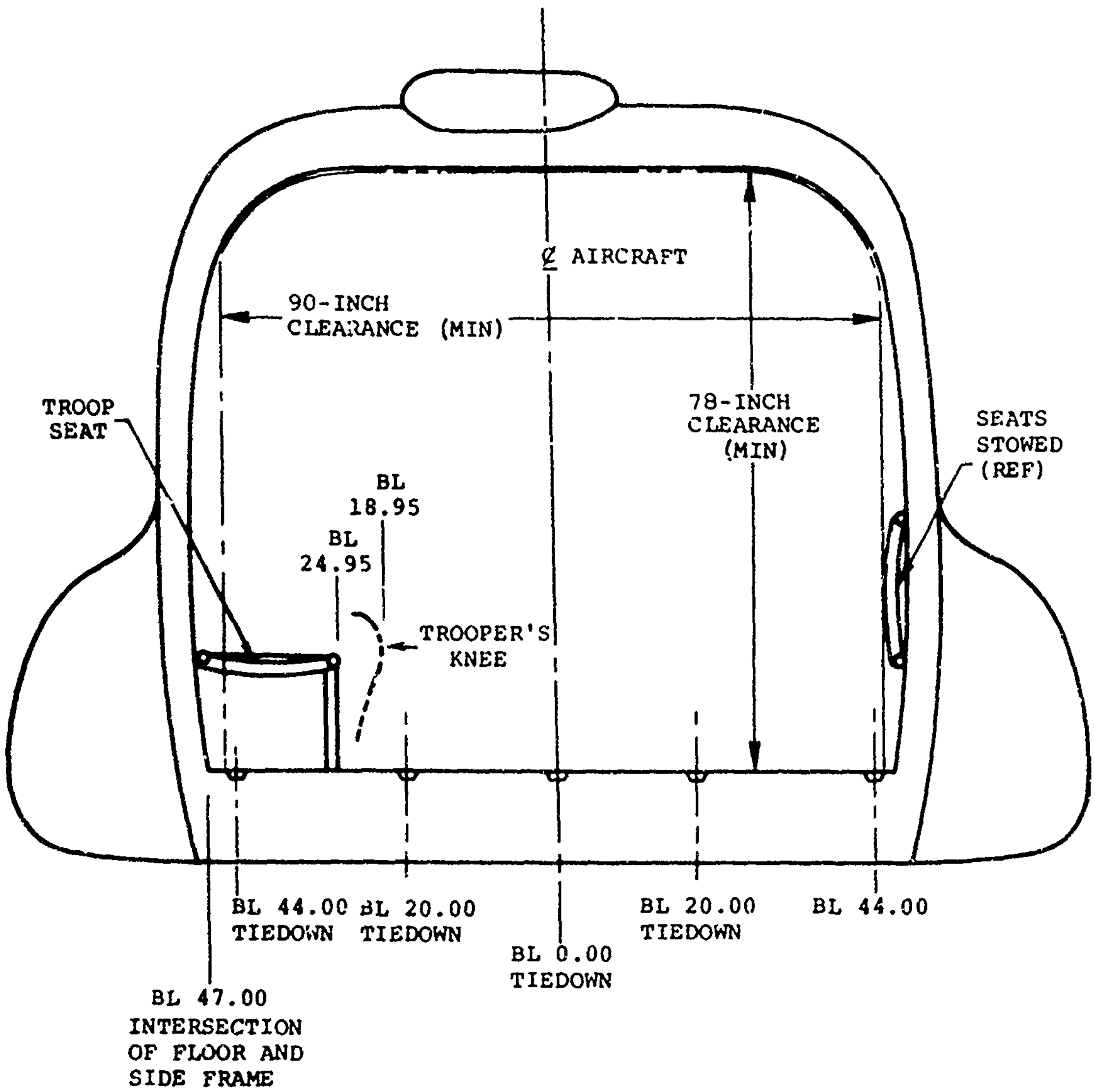


Figure 79. CH-47 Cabin Cross Section Showing Dimensions Used for Determining Lateral Stroke Limitations of Cargo.

Vertical depth under the cargo floor was another consideration in selecting the longest practical energy absorber stroke. An 8-inch stroke was selected on the basis of available vertical subfloor depth which includes clearance for installation.

Required subfloor depth is available for 83 percent of the floor tiedown locations. In fitting locations where clearances less than 8 inches exist, an alternate means of positioning the load limiters to obtain the full stroke for longitudinal load restraint will be investigated.

Use of an 8-inch rather than a 6-inch cargo deflection also results in a reduction in design g level as shown below:

Cargo and Load Direction	Required Restraint G Level*		Survivability Percentile Level
	6-Inch Stroke	8-Inch Stroke	
Class A			
Longitudinal	12.8	11.0	90th
Lateral	5.5	4.8	90th
Class B			
Longitudinal	8.0	7.2	80th

*See References 12 and 14.

When vehicles are carried internally as cargo, passengers must be confined to forward and aft locations. This is due to the lack of adequate space for cargo stroking between vehicles and aircraft structure. When pallets, loose cargo, POL drums, and other Class A items are carried, passengers may be arranged anywhere around the cargo, as long as sufficient stroking distance is available.

3.6 DYNAMIC RESTRAINT LOAD FACTORS

As described in Section 3.3, the maximum dynamic restraint system g load factors are to be determined at the 90th percentile level of crash survivability for the longitudinal and lateral impact directions. The corresponding cargo stroke requirement is predicated on either the design limitations of the restraint device used or the minimum available clearance between the cargo and people, or cargo and airframe structure (see Tables VIII and IX). Since g load factors are also dependent on the material characteristics of the cargo restraint system, the criteria must be exploited for the two basic types of restraint systems pertinent to aircraft application. They are: 1) existing nylon webbing devices carried with U.S. Army aircraft, and 2) constant load attenuation devices

combined with low-elastic tiedown devices or nets. Their corresponding g load factors, discussed and calculated below, are tabulated in Table X. For convenience, the data for static restraint g load factor (from Section 3.7) is incorporated in this table.

TABLE X. COMPARISON OF DESIGN LOAD FACTORS FOR PRESENT AND RECOMMENDED RESTRAINT SYSTEMS

Restraint System	Dynamic Restraint g Load Factors for 90 Percentile Level of Survivability		Static Restraint g Load Factor
	Longitudinal Impact Direction	Lateral Impact Direction	Vertical Up Impact Direction
Existing nylon webbing (rated 5,000 lb/ft)	36	17.5	5
Low-elastic devices with load attenuators (for 8-inch stroke)	11	5	3.75

Existing Nylon Webbing Devices (5000-pound capacity)

Nylon webbing devices are used as tiedown units between cargo and floor. The maximum stretch for a device depends on the length utilized, since the unit is rated at an estimated 5000 pounds for 25 percent elongation (see Reference 29). Assuming a length of 4 to 6 feet, at 5000 pounds the device will deform 12 to 18 inches. Lateral clearance between cargo and airframe structure (see Table VIII) varies from 10 to 25 inches, with the majority oof cargo clearances above 11 inches. The only exception is the M107 water trailer, for which clearance is limited to 6 inches. However, for g load computation purposes, a 12-inch stroke will be assumed to be prevalent. It appears (see Table IX) that a 12-inch stroke is also attainable for the longitudinal direction if the proper troop seating arrangement is used. The cargo g load for longitudinal restraint at the 90th percentile level of survivability is computed using equations (13) and (15) and Figure 10.0 from Reference 29. These equations pertain to the amplitude and frequency of vibration parameters derived for extensible restraint devices. These parameters are rearranged as Equation (14):

$$C^2 = \frac{T^2 n^1}{\pi^2 \Delta} C_1 \qquad (14)$$

where n^1 = peak impact g level of 20 and replaces A in (Reference 29) Equation (15)

Δ = cargo restraint stroke of 1 foot and replaces Amp in (Reference 29) Equation (15)

T = impact pulse duration, 0.158 sec

C = constant pertinent to the frequency of vibration

C_1 = constant pertinent to the amplitude of vibration

then
$$C^2 = \frac{(0.158)^2 \ (20)}{\pi^2} C_1 \qquad (15)$$

$$C^2 = 1.63 \ C_1$$

Assuming $C_1 = 1.80$, then

$$C^2 = 2.94$$

$$\text{or } C = 1.715$$

From (Reference 29) Equation (13),

$$K = C_1 n^1 W \qquad (16)$$

where W = cargo weight

Therefore, the dynamic g load factor n is 1.8 x 20, or 36. Similarly, for the lateral impact direction, the cargo g load factor is 17.5.

Load Attenuator with Low-Elastic Webbing Devices

For a load attenuator device stored below the CH-47 helicopter floor level as an integral part of the airframe, the maximum available stroke is estimated at 8 inches (see cargo stroke determination section). Above the floor level the design stroke of the device (e.g., load limiters in series with straps) is solely predicated on cargo clearance factors. Assuming a design stroke of 8 inches and utilizing the load-deflection curves depicted in Figures 76, 77, and 78, the longitudinal and lateral g load factors required for restraining cargo with load limiting devices are 11 and 5, respectively. The use of the low-elastic webbing devices with load attenuators tends to minimize the cargo stroke during operation - the cargo

stroke being equal to the sum of the deformation of the strap and load limiter devices. See the Reference 29 and 31 reports for further documentation on this subject.

3.7 STATIC RESTRAINT LOAD FACTORS

As described in Section 3.4, a 5g static load factor was selected for vertical up restraint; vertical down restraint is based on floor characteristics. This static load factor was obtained from Reference 31 and is based on a possible rebound load from a vertical deceleration of 20g. It appears that the 5g static load factor is reasonable for a restraint system (such as the existing nylon webbing type) without load limiting devices. However, since limiting devices are unique in their load application, a reduction in the g level for the rebound load is possible.

To determine the equivalent vertical g load factor n_1 for load attenuation devices, the total work required (during vertical down crashes) to deflect the cargo floor a dimension d is equated to the total work required for nylon webbing devices (without load limiting devices) to sustain on rebound. The rebound energy is the area under the nylon webbing load-deformation curve (see Figure 80). Therefore,

$$nWd = \frac{PS_n}{2} = \frac{5WS_n}{2} \qquad (17)$$

or

$$d = 5/2\ \frac{S_n}{n} \qquad (18)$$

where
- P = 5g static load factor times cargo weight
- S_n = nylon webbing deformation, 12 in.
- W = cargo weight
- n = vertical down g load factor due to impact condition

then

$$d = 30/n$$

For the low-elastic strap combined with load attenuators, the total work required to deflect the floor is equated to the total work the load attenuators will sustain on rebound; therefore, with the use of Equation (18),

$$nw\ \frac{30}{n} = n_1\ WS_1 \qquad (19)$$

or

$$n_1 = \frac{30}{S_1} \qquad (20)$$

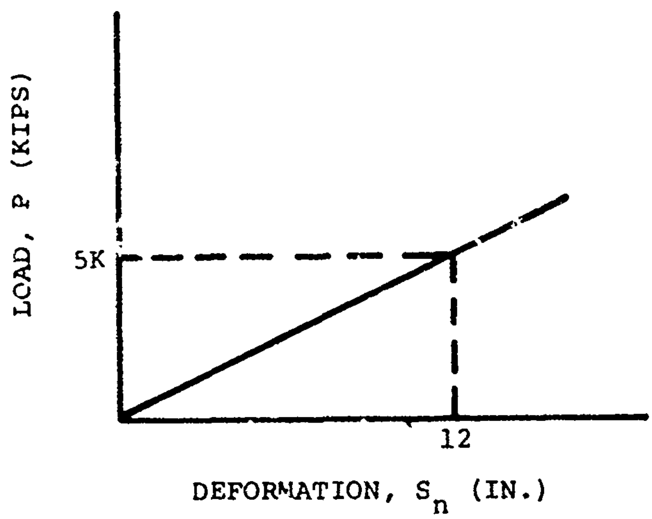


Figure 80. Estimated Nylon Webbing Load-Deformation Curve.

For a constant load-deflection curve, n_1 is the load limiter g load factor and S_1 is the load limiter stroke (8 inches). Then

$$n_1 = 30/8$$

$$n_1 = 3.75$$

3.8 CRASH SURVIVABILITY FOR MINIMUM RESTRAINT TECHNIQUES

This section was derived because the existing Army techniques of restraining cargo are based on static criteria and, when transformed to dynamic criteria, will result in less than the desired 90th percentile level of survivability. In addition, during combat operations, limited time is available to correctly restrain cargo for full crew protection. Consequently, the crash survivability-tiedown envelope attainable by using minimum cargo restraint must be determined.

The data in Table XI is delineated to establish the longitudinal and lateral floor pulses at various percentile levels of survivability. Using this and other data from the restraint systems studied, cargo weight for a single cargo tiedown application, along with cargo g level as a function of percentile of survivability, was calculated and plotted (see Figures 146 through 151). The relationship between the crash pulses or the associated survivability level (Table XI) and minimum restraint techniques is illustrated by a simple example. Suppose a minimum tiedown system consisted of one strap device with a 7.5k load attenuator restrained for longitudinal impact. A package weighing 2000 pounds will result in a survivability level of about 61 percent (Figure 150) and a cargo g level of 3.5 (Figure 148). This shows that a great deal of protection can be afforded the crew during combat or other operations employing minimum restraint techniques. Other examples can be found in Section 7.4.2. However, for operations where maximum protection to the crew can be accomplished, the restraint criteria load factors depicted in Table X should be given full consideration.

TABLE XI. LONGITUDINAL AND LATERAL IMPACT PULSES AT CABIN CARGO AREA

Percentile of Survivability	95th	90th	80th	70th	60th	50th	40th	30th	25th
Longitudinal Impact Pulses*	27G	20G	16G	8.5G	5.43G	4G	3.2G	3G	2.6G
ΔV in fps →	60	51	44	39	35	32	29	25	23
Lateral Impact Pulses**	16G	10G	9.6G	4.46G	3.7G	2G			
ΔV in fps →	25	21	18	16	14	13			

* Pulses developed from report AD 656621
** Pulses estimated with the aid of report AD 656621
ΔV Impact velocity change during crash condition

4. CH-47 HELICOPTER STRUCTURAL ANALYSIS

An analysis was performed to determine the extent to which the CH-47 cargo supporting structure is capable of restraining cargo during survivable crash conditions. The pertinent structural material characteristics related to plastic deformation are utilized to develop the structure to its full potential. The design pulse-duration envelope and the design load-stroke requirements presented in Section 3, DESIGN CRITERIA, are used as the basis for the analysis so that a predicted energy level for restraining cargo may be studied. Also, a comparison is made between cargo load levels that will maintain the structural integrity and the load levels that could be obtained when allowing the structure to deform.

Helicopter structural components are designed as high-strength low-elongation type structures which are predicated on the present flight static load criteria. In addition, a high stiffness type structure is generally required to maintain acceptable helicopter vibration levels. The structural design techniques applied to the present flight static criteria will not necessarily apply to the predicted survivable dynamic crash loads imparted to the CH-47 helicopter. In order that cargo and associated cargo restraints react to acceptable load levels within the energy levels imposed by the impact condition, the supporting structure must be designed to relatively soft or low-strength high-elongation characteristics. The important cargo load supporting structures that are studied in detail are the floor tiedown fittings, floor structure, floor frames, and side frames. Figure 81 shows the general CH-47 structural arrangement.

4.1 FLOOR TIEDOWN FITTINGS

The CH-47 floor tiedown fittings, which distribute cargo loads into the floor structure and floor frames, are rated at a 5000-pound capacity. The 5000-pound rated value occurs when the D-ring component of the tiedown fitting is tied at an angle close to the floor surface (see Figure 82), which results in an eccentric load producing moment between the fitting and floor frame cap. The moment is reacted as a couple by fitting to floor-frame bolt attachments and compression between fitting and frame. When considering the four bolts loaded to their ultimate capacity in a symmetrical manner (see Figure 82), the total resultant load of 4 x 4570 (see Figure 82), or 18,280 pounds, is excessively higher than the D-ring structural component capability estimated at 7500 pounds. Static test failure values of 5050 to 5150 pounds have been obtained (Reference 2), and field observers have indicated that bolt tension is the primary mode of failure. The tiedown fittings are very

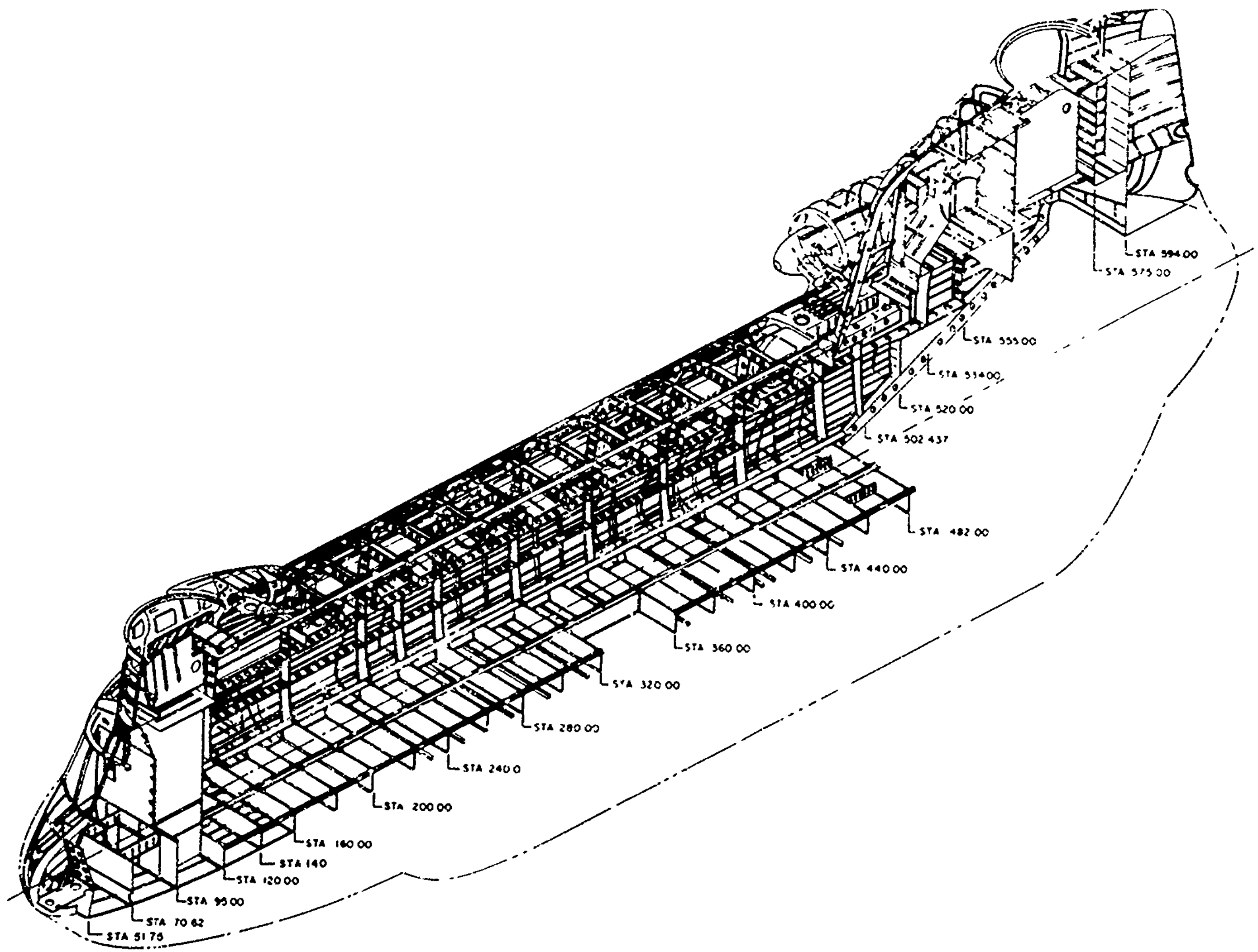


Figure 81. CH-47 Structural Arrangement.

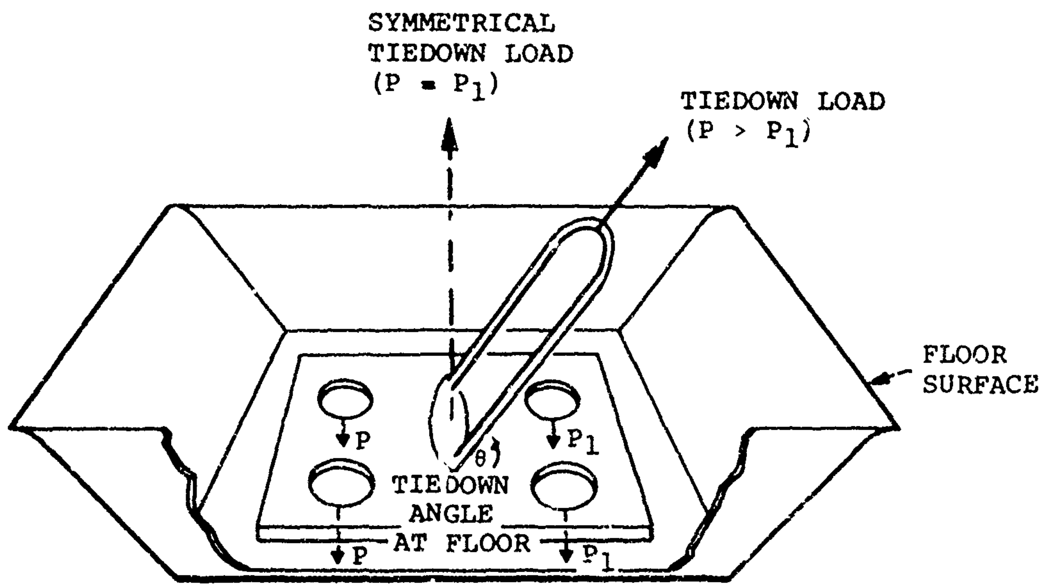


Figure 82. CH-47 Floor Tiedown Fitting.

rigid and will respond only to relatively low energy levels. This is verified by summing up the area under the load deflection curve (see Figure 83) for the bolt material. The total energy level per bolt u is 4570 (.015-.0063) + 1/2 (4570)(.0063) or 54 inch-pounds. Using Equation (24), it is estimated that the D-ring at failure is capable of 1500 inch-pounds of energy, which is relatively low when compared to the predicted cargo impact energy level of 60,000 inch-pounds. It is apparent that the tiedown fittings are not very efficient as energy absorbing devices and will not respond favorably to dynamic impact energy levels depicted in Section 3, DESIGN CRITERIA.

4.2 STRUCTURAL FLOOR AND FLOOR FRAMES

The floor structure is constructed of continuous I-sections and inverted hat sections (see Figure 84) utilized as a recess area to store the tiedown rings below floor level when not in use. A large portion of the floor is isolated from the adjacent structure to reduce helicopter vibrations. This is accomplished by the installation of rubber isolator pads between the floor and the top caps of the floor frames (see Figure 84). The isolated flooring at the fore and aft ends is transitioned into fixed flooring which is rigidly attached to pertinent structure (Figure 85).

Within the envelope of the isolated and fixed floor area mentioned above, there are fifty-four 5K capacity tiedown fittings patterned to a 3 by 18 matrix on 20-inch centers along the lateral and longitudinal helicopter axes, respectively (see Figure 85). An additional fifteen 5K and four 10K fittings exist along each side of the aircraft floor adjacent to the isolated floor area depicted in Figure 85. In the isolated portion of the floor, each tiedown fitting is bolted to bushings through the floor frame cap to allow vertical floor movement. The same fitting is also attached to the floor structure through a receptacle (see Figure 84). In nonisolated areas, the bushings are removed and the bolts are tied directly to the frame cap.

Longitudinal Cargo Loads for Isolated Floor

For longitudinal cargo loads in the vicinity of the isolated floor structure, the tiedown fittings transfer the load intensity directly to the floor structure along its forward and aft axes. The vertical load component that exists when the cargo restraint device is tied at an angle to the floor surface is carried by the floor frame in bending. The load in the floor will be carried in tension aft of the tiedown fittings and in compression forward of the tiedown fittings. However, because of the floor stiffness characteristics, most of the load will travel to the tension side, where it will be reacted through the fixed flooring end of the structure and sheared outboard to the fuselage shell (see Figure 86).

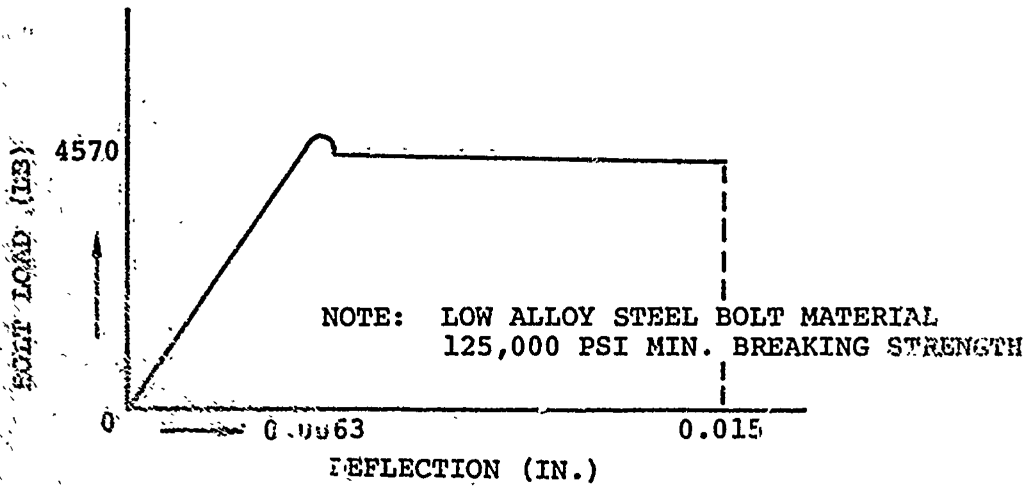


Figure 83. Load-Deflection Curve for 0.25-Inch-Diameter Bolt, 1.5 Inches Long.

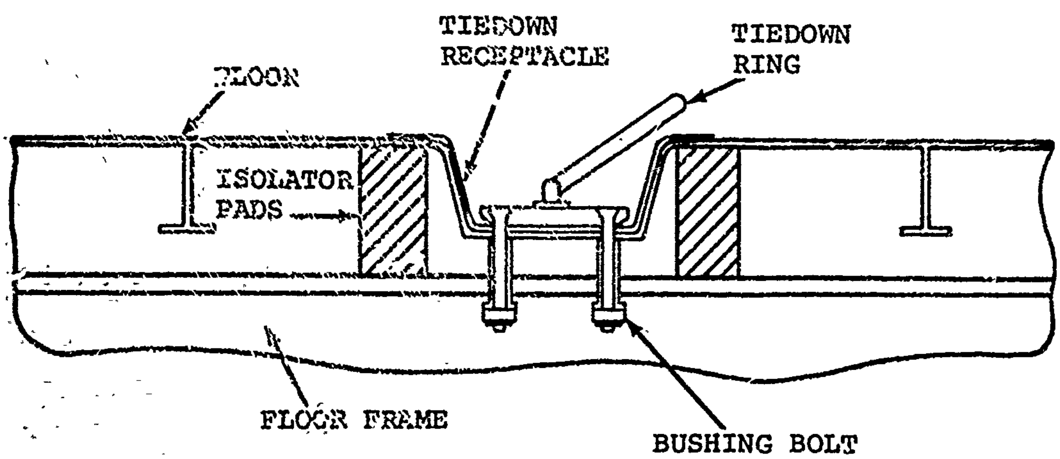


Figure 84. CH-47 Floor Section Tiedown Ring and Floor Frame.

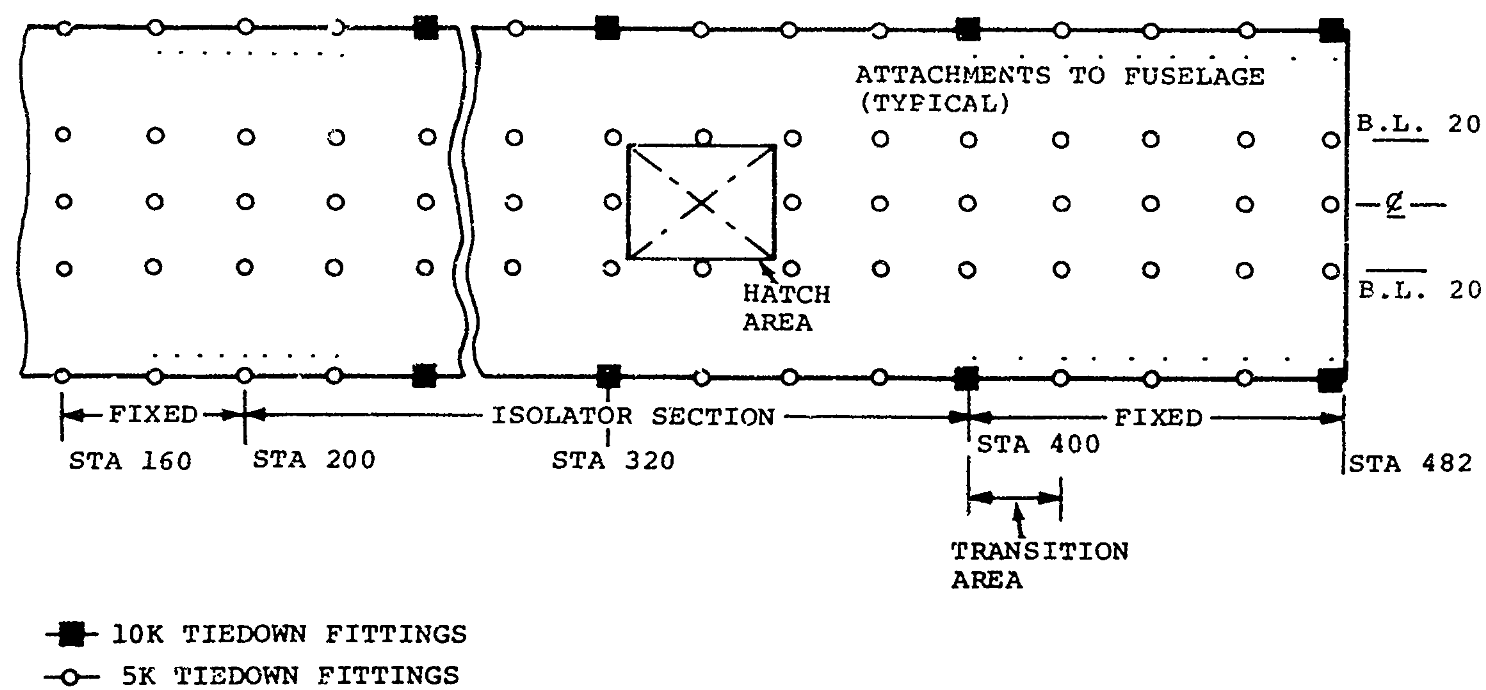


Figure 85. Plan View of CH-47 Floor.

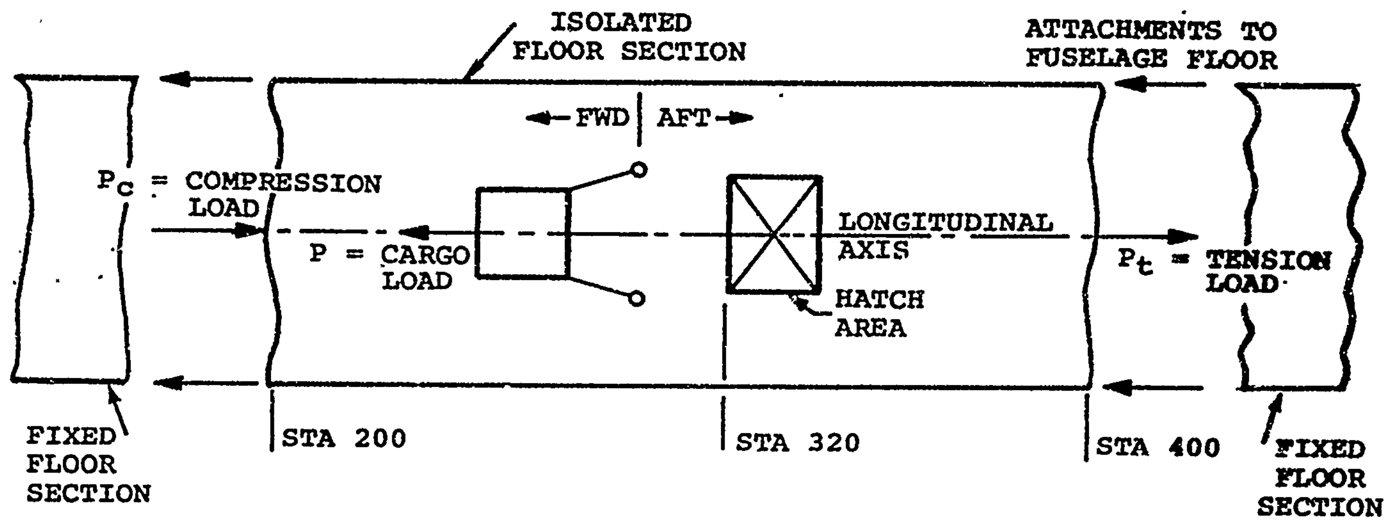


Figure 86. Plan View of Cargo Tied to CH-47 Floor.

The following theoretical analysis pertinent to both the floor structure and floor frames facilitates the Category II pulse-duration envelope defined in Table VII of Section 3, DESIGN CRITERIA. For convenience, a 1250-pound package and an 8g level corresponding to a cargo stroke of 6 inches were selected, which results in a total restraint energy requirement of 60,000 inch-pounds. (See Figure 77.) It is further assumed that the vertical load component from the cargo restraint device is small and consequently neglected.

From the floor structural material (ZK60A-T5 magnesium alloy extrusion) stress-strain curve (Reference 42), the curve of Figure 87 was delineated. The values along the vertical axis of the curve were obtained using an area of 6.6 square inches (adjusted for the hatch hole in the floor), and the deflection axis was based on a floor length of 100 inches and the assumption that about 50 percent of the total length of the isolated floor section was in tension. (See Figure 86.)

Summing up the area under the curve corresponding to 60,000 inch-pounds of energy results in a load of 218,000 pounds for 0.55 inch of deflection. This load is in excess of the load capacity of the attachments tying the fixed portion of the floor structure to the side fuselage shell. The floor is retained at each end by 20 screws; each screw is capable of an ultimate single shear capacity of approximately 2200 pounds. At this load intensity, immediate failure would occur and the floor on the forward side of the floor fittings would tend to buckle. The buckling or compression load is calculated from the equation

$$Pcr = \frac{\pi^2 E_r I}{L^2}, \tag{21}$$

and

$$E_r = \frac{4E_t E}{(\sqrt{E} + \sqrt{E_t})^2} = 6.16 \times 10^6 \text{ psi} \quad \text{(Reference 26)} \tag{22}$$

where L = length between floor frames, 20 in.
E_t = 5.79×10^6 psi (Reference 43)
E = 6.5×10^6 psi for ZK60A-T5 magnesium extrusion
I = 1.210 in.^{4}

Then

$$Pcr = \frac{\pi^2 (6.16 \times 10^6)(1.210)}{400} = 184,000 \text{ pounds}$$

As previously indicated, the attachments containing the floor are of much lower capacity (44,000 pounds) and will fail before the buckling load is realized. Then, the pertinent floor frames will support the floor with the longitudinal load reacted by the upper frame cap (see Figure 88). The upper frame cap will tend to act as a bending member of an approximate length equal to the total width of the floor (see Figure 89).

The beam is capable of approximately 45,000 inch-pounds of energy with a total tiedown load of 1460 pounds, which is insufficient to accomplish the degree of restraint required. The equation utilized to determine the energy level is a form of the basic theoretical beam energy equation, which is:

$$U = \frac{1}{2} \sum \frac{M^2 \, dx}{EI} \tag{23}$$

where M = bending moment
dx = finite beam length
E = modulus of elasticity
I = moment of inertia
U = strain energy

For plastic analysis with impulsive type loading, the equation is revised to:

$$U = \sum \frac{M^2 \, dx}{E_t \, I} \tag{24}$$

where E_t = tangent modulus

Equation (24) is approximate, and its method of application can be utilized effectively. From past experience, the calculations pertinent to Equation (24) are reduced to a minimum. The beam frame cap cross section properties are shown in Figure 90.

The plastic moment is defined by

$$M = S\ A\ h \tag{25}$$

where M = internal bending moment
S = ultimate stress
A = section area associated with the yield stress
h = moment arm associated with the internal bending moment M

Assuming two tiedown locations, 40 inches apart, which is equivalent to a strap wrapped around a package and tied to these fittings, and a beam length of 90 inches, then the total restraint load is:

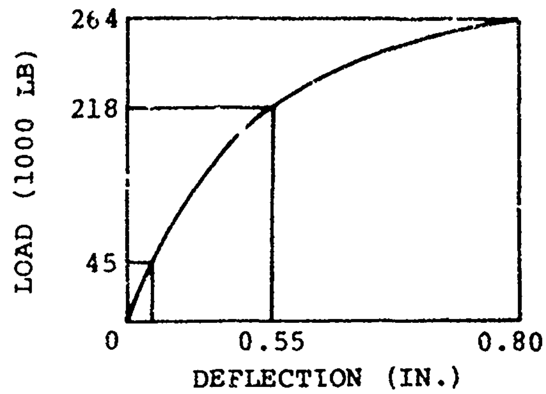


Figure 87. Load-Deflection Curve for CH-47 Floor Structure of ZK60A-T5 Magnesium Alloy Extrusion.

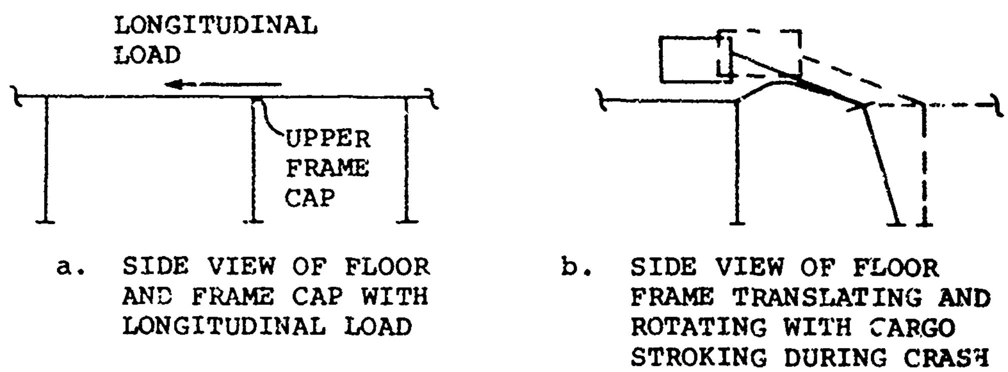


Figure 88. Longitudinal Load Deflection of CH-47 Floor.

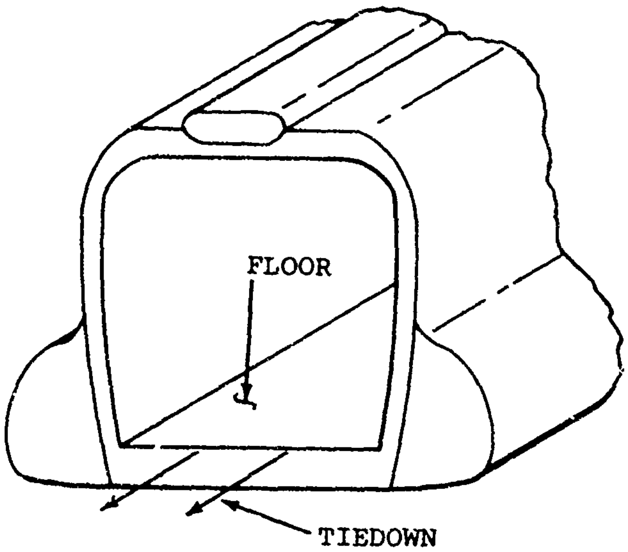
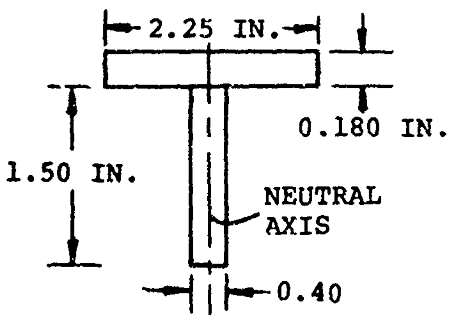


Figure 89. Upper Cap of CH-47 Floor Frame Acting as Bending Member.



$$I = \frac{(2.25)^3\ (0.110)}{12} = 0.171\ \text{IN.}^4$$

MATERIAL: 7076-T6 ALUMINUM ALLOY EXTRUSION

$F_{TU} = 80{,}000$ PSI

Figure 90. CH-47 Frame Cap Section Properties.

$$P = \frac{2M}{25} \tag{26}$$

$$P = \frac{(2)\ [80,000\ (1.125)(.18)(1.125)]}{25}$$

$$P = \frac{(2)\ (18,250)}{25}$$

$$P = 1460 \text{ pounds}$$

The energy level is obtained by using the minimum tangent modulus of 2×10^6 psi and a total effective length of 1.15 times the length between the tiedown loads (40 x 1.15), or 46 inches. This is predicated on the assumption that the beam is loaded in the plastic range between the load points and the increase in increment length accounts for the remainder of the beam's acting in an elastic-plastic load range. Consequently, the energy level is approximately

$$U = \frac{(18,250)^2\ (46)}{(2\times10^6)\ (.171)} = 45,000 \text{ inch-pounds} \tag{27}$$

The resultant deflection is 45000/1460, or 31 inches. The above calculations indicate that a rapid drop in the restraint load with a large stroke is imminent. However, the floor frame will translate and rotate, transforming the longitudinal load from the frame cap in bending to the floor frame as a beam in bending, utilizing both upper and lower caps (see Figure 88). Most of the cargo restraint load will be reacted by the floor frame beam while a relatively smaller component of this load will be reacted by the floor along its forward and aft axes. This is attributed to the fact that the beam will tend to line up with the cargo strap perpendicular to the floor frame beam's bending axis.

Very little energy was absorbed by the above-mentioned structure; therefore, the floor frame will have to absorb the 60,000 inch-pounds of energy. The resultant moment using Equation (24), assuming two tiedown fittings with effective length of 46 inches and utilizing the pertinent parameters given in Figure 91, is:

$$M = \left[\frac{60,000\,(6.2\times10^6)\,(52.57)}{(46)}\right]^{1/2} = 653,000 \text{ inch-pounds}$$

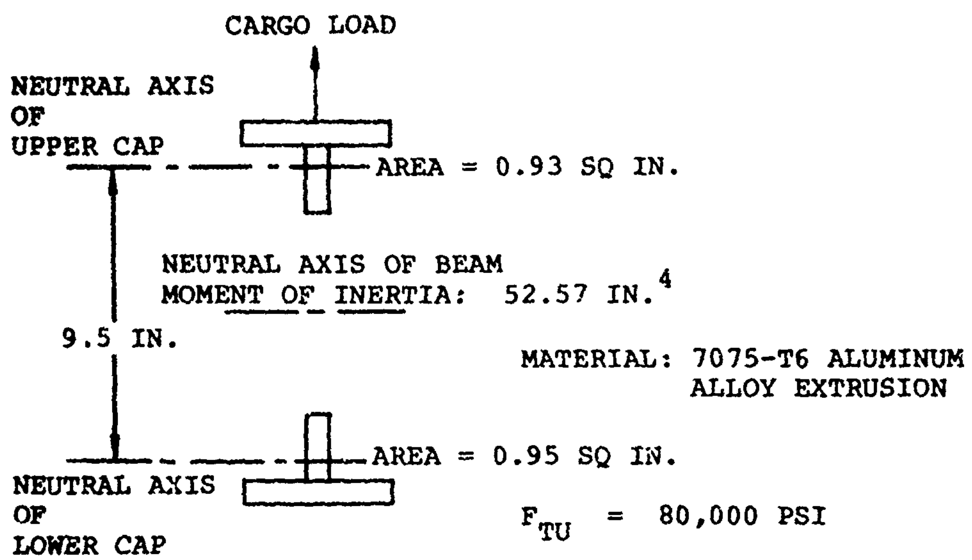


Figure 91. CH-47 Floor Frame Cross Section Depicting Upper and Lower Caps.

The value of 6.2 x 10^6 for E_t was obtained through trial and error analysis using the aluminum alloy stress-strain curve and its tangent-modulus curve (Reference 42) with the corresponding stress level occurring at 74,000 pounds per square inch. The total cargo restraint load is (653,000 x 2)/(25) or 52,200 pounds, and the restraint deflection is 60,000/52,200 or 1.15 inches.

The above data was consolidated and delineated into a g level-deflection curve depicted in Figure 92. Also included is the usable load-deflection curve, which was the basis for the previous analysis. The total movement of the cargo due to the floor frame rotation and translation at time of floor attachments failure is not depicted in Figure 92 because a small amount of working energy is realized. However, during this transition interval, the cargo movement could be substantial when compared to the floor frame deflection of 1.15 inches. The 42g level attained by the floor frame is substantially higher than the 13g peak load defined by the pulse curve (see Figure 77) used to derive the usable 8g load. This indicates that the existing aircraft support structure is relatively stiff and imposes relatively high loads on the cargo and the restraint devices tying cargo to floor fittings. For example, an Army jeep weighing 2660 pounds would require a total restraint load of 112,000 pounds where the preselected usable 8g load would require a restraint load of 21,300 pounds. The floor is inefficiently designed for crash pulse loads because the frame material is not utilized to its full plasticity characteristics at the defined energy level. This is attributed to the high load level that results when deforming at its yield level. The floor structure, if allowed to deform without attachment failure (see Figure 92), will respond with a relatively higher load intensity than the floor frames (175g), which is well above the usable limit.

When considering the dynamic crash conditions, it is apparent that the floor structure and floor frames are overstrength. A correlation between normal flight conditions and crash environments is necessary to effectively design the supporting structure.

Lateral Cargo Loads for Isolated Floor

For lateral or side crash conditions, the floor structure acts as a beam 200 inches in length (see Figure 93). For purposes of calculation, it is assumed that a 3-inch stroke is required, which is relative to a usable 7.0g level obtained from the curve of Figure 78 in the DESIGN CRITERIA section. The total required energy using a 1250-pound package is then 26,200 inch-pounds. Using the appropriate stress-strain curve (from Reference 4) and Equation (24), the required structural internal moment using two floor tiedown locations (see Figure 93) is:

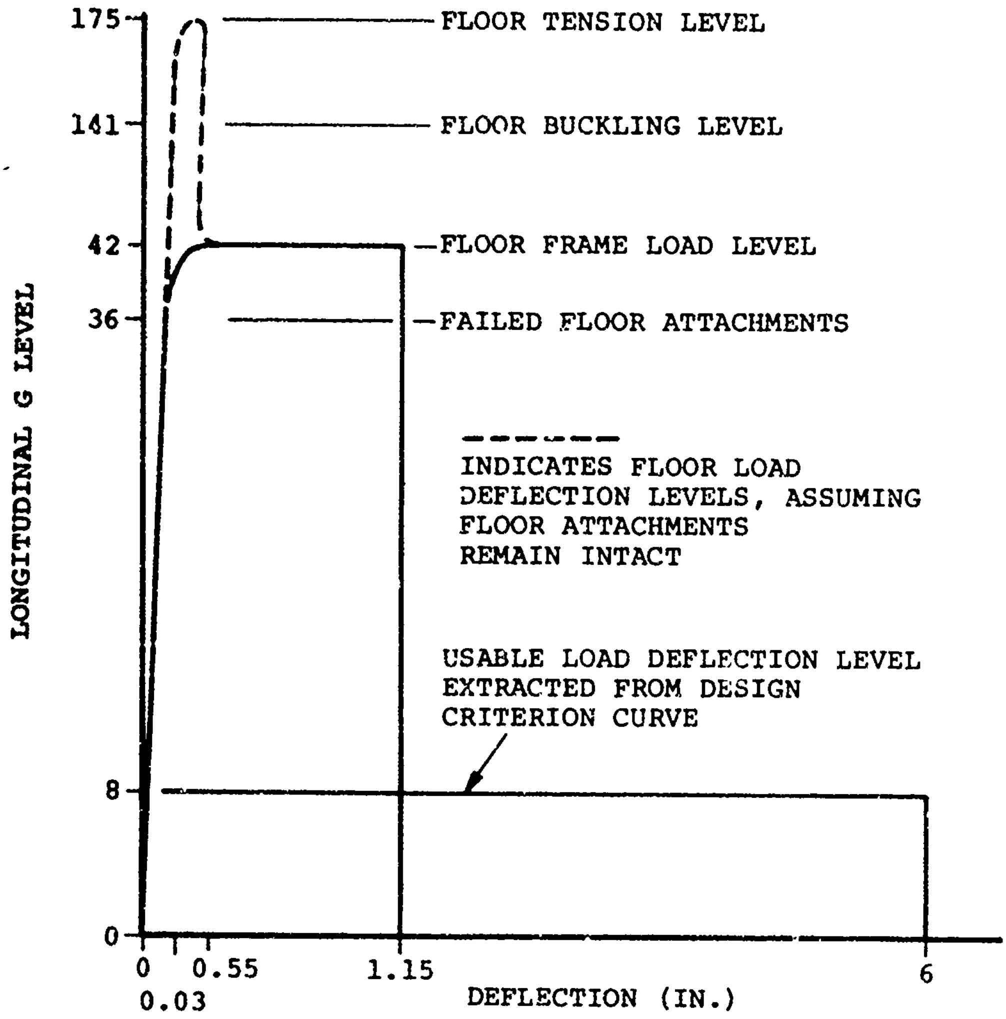


Figure 92. CH-47 Supporting Structure Load-Deflection.

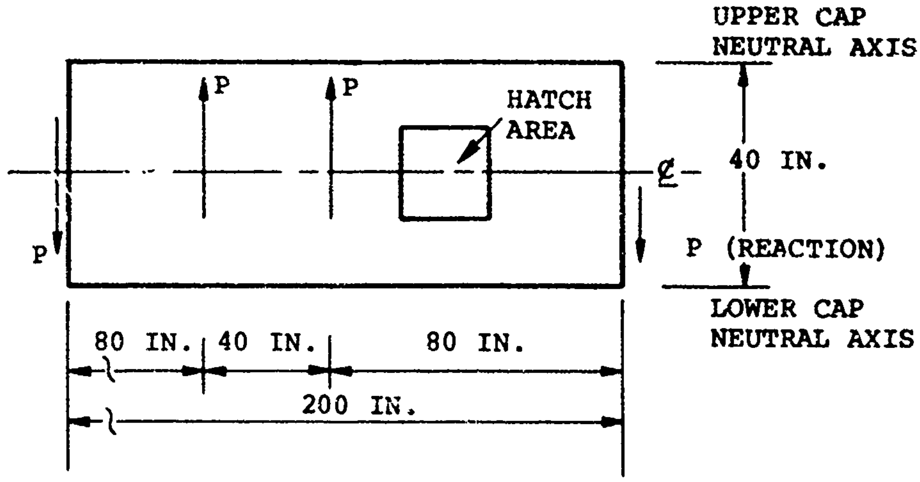


Figure 93. Plan View of CH-47 Floor Structure With Lateral Cargo Loads.

$$M = \left[\frac{U\ E_t\ I}{\ell}\right]^{1/2} \tag{28}$$

$$M = \left[\frac{26{,}200\ (3.5 \times 10^6)(5470)}{48}\right]^{1/2}$$

$$M = 3{,}220{,}000 \text{ inch-pounds}$$

where U = 26,200 in.-lb

E_t = 3.5×10^6 psi

I = 5470 in.^{4}

ℓ = 48 in., effective length

The total cargo load 2P is (3,220,000 x 2)/80 or 80,000 pounds.

The corresponding stress level is 35,000 psi, which is about 22 percent below its ultimate stress value of 45,000 psi (ZK60A-T5 magnesium alloy extrusion). The equivalent g level load factor is 80,000/1250 or 64, and the beam deflection is 26,300/80,000 or 0.33 inch.

The 64g force level is considerably higher than the usable 7g intensity which would impose relatively high loads on the cargo. Any sizable deflection by the existing floor would transfer the load primarily to the floor frame upper cap as an axial applied load. This would tend to be a stiffer load path and would result in an even higher g level, which is definitively unacceptable when compared to the usable g level as depicted in the design criteria. In addition, the calculated 64g level is much higher than the 10g lateral crash impulsive force, which increases rather than decreases the magnitude of load to be reacted by the cargo and its tiedown restraints.

Cargo Loads for Fixed Floor

For packages tied to the floor tiedown fittings in the fixed portion of the floor area, the crash loads will tend to be reacted by the floor frame upper cap members which are tied directly to the floor fittings. For a longitudinal crash force, the upper cap will tend to bend and transfer the load to the floor as an axial load which is a stiffer load path. This is similar to the isolated floor loading described above. The lateral crash load will be reacted by the floor frame upper cap as an axial load with a small percentage of the load carried by the floor. This is attributed to the frame upper cap being relatively much stiffer when acting as an axial

member. The g level, if calculated, will be relatively high, as the foregoing structural floor and floor frame analysis indicates; therefore, no further analysis is undertaken.

4.3 SIDE FRAMES

The side frames are basically sheet metal type structure spaced about 40 inches along the CH-47 helicopter's longitudinal axis throughout the cargo cabin area. These frames are constructed integrally with the floor frames and are attached to the fuselage shell. Considering the frame as a detachable structure from the fuselage and with a typical frame cross section as shown in Figure 94, the maximum energy level for a lateral crash condition (Figure 95) using Equation (24) is

$$U = 2 \int_0^{17.5} \frac{(Px)^2\,dx}{E_t\,I} \quad 3600 \text{ inch-pounds} \qquad (29)$$

where l = effective length of 35 in. assumed for elastic-plastic load range

x = l/2 or 17.5 in.

E_t = 2×10^6 psi (lowest tangent modulus)

I = 2.0 in.^4 (moment of inertia of total section)

$p = \frac{80,000(0.35)(2.85)}{40} = 2000$ lb total restraint load

This assumes that locally the side frame is tied to the cargo with a single device and acts as a simple beam 40 inches in length. The corresponding load deflection is 3600/2000 or 1.80 inches.

From the lateral g level deflection curve depicted in the DESIGN CRITERIA section (see Figure 78), an 8.5g load factor corresponds to 1.80 inches of deflection. This means that a side frame is capable of restraining a total package weight of 2000/8.5 or 235 pounds. Using two adjacent frames restrained to a single package, the total cargo weight of 470 pounds can be restrained at failure for the predictable lateral crash condition. Tying two or more tiedown devices to a single frame will undoubtedly increase the energy absorption capability of the restraint system. A multiple tiedown system for proper restraint will depend on the tiedown fitting location at the side frame. For example, a side frame tiedown fitting near the floor area will add appreciable structural stiffness since the juncture of floor frame, floor structure, and side frame is near this location. In addition, multiple

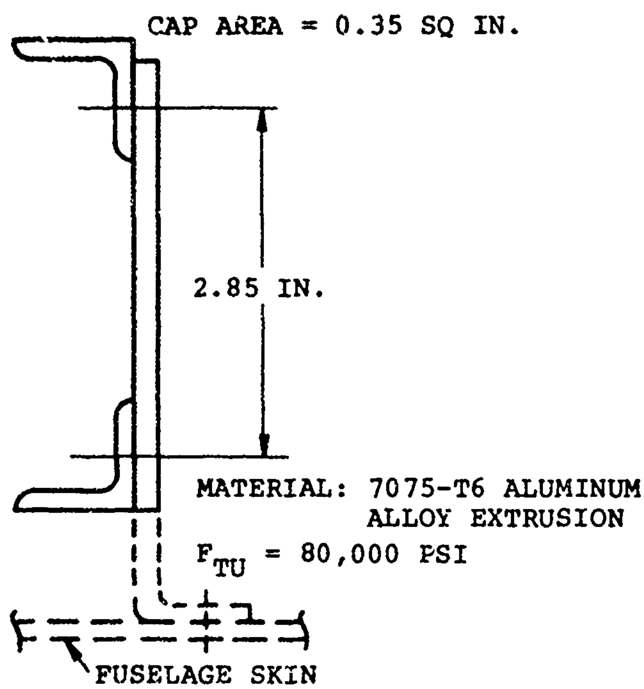


Figure 94. Side Frame Cross Section.

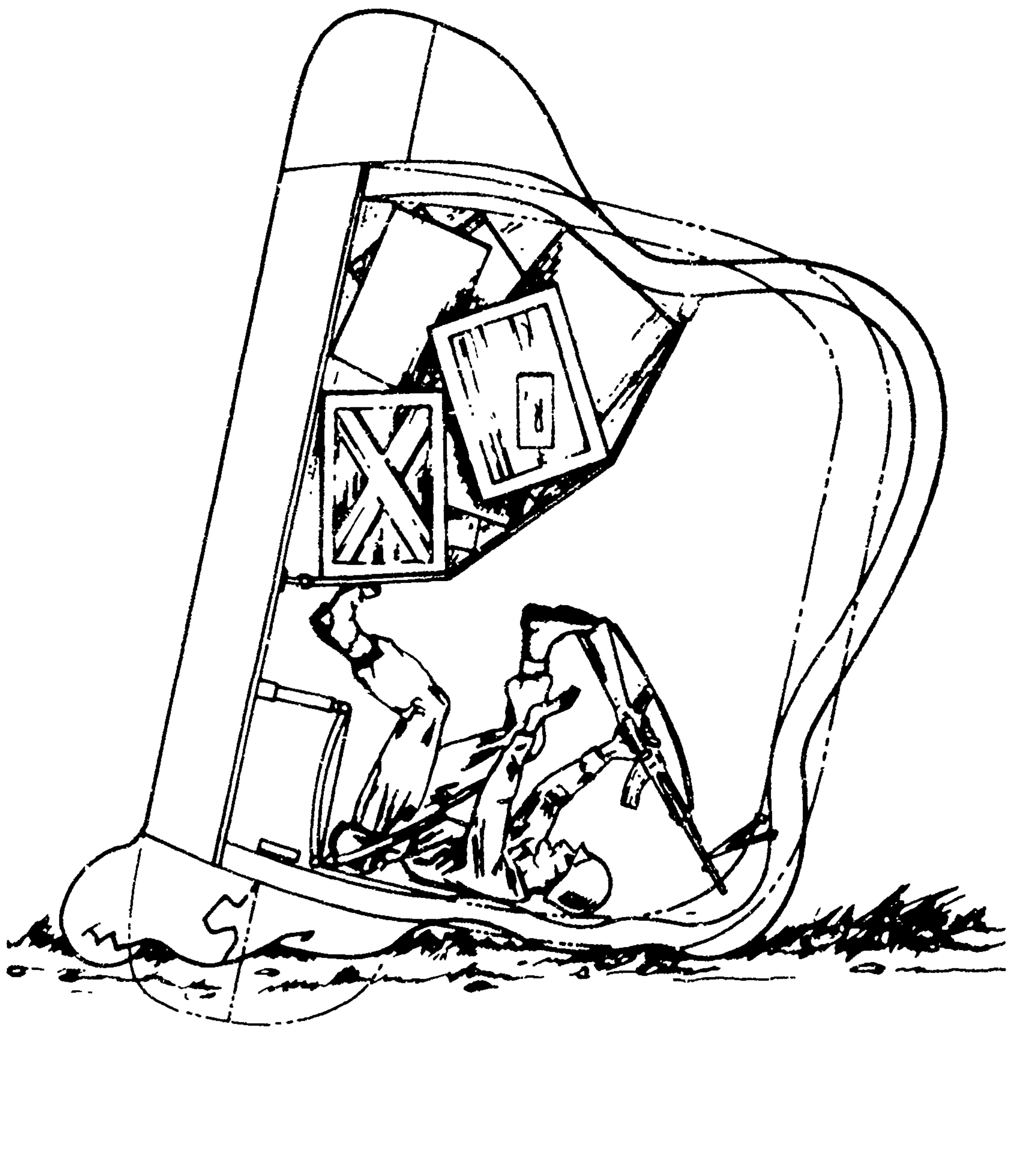


Figure 95. Lateral Crash Event Showing Personnel and Cargo Tied to Side Frames.

tiedown restraints will be adversely affected by the restraint elasticity problems which are associated with the angle the restraints make with the cargo and with the variant restraint lengths that result from tiedown fitting locations relative to the cargo. A detailed discussion on problems associated with restraint characteristics can be found in Reference 21. The attachments of the side frame to the fuselage shell will contribute added stiffness to the structure, and, in all probability, will reduce its energy absorption capability and increase the total load to be imposed on the cargo.

4.4 RESULTS OF ANALYSIS

From the above theoretical analysis, it is concluded that:

1. The use of the structural floor, floor frames, or side frames as the cargo load supporting structure with the proposed survivable crash restraint criteria is not feasible.

2. The current floor tiedown fittings and backup structure are very rigidly constructed; consequently, they are not usable as energy absorbing devices.

3. Existing static design philosophy is not compatible with the proposed dynamic crash criteria.

5. CANDIDATE CARGO RESTRAINT SYSTEMS

The purpose of this section is to comprehensively develop candidate integral helicopter cargo restraint methods and techniques which use the load attenuation concept. To be considered, the cargo restraint systems must have maximum practical energy absorbing capability and be responsive to the requirements set forth in the DESIGN CRITERIA section.

The candidate restraint systems are presented in three general categories:

- Category I - Provide energy absorption capability for cargo restraint without aircraft modification.
- Category II - Integrate energy absorption capability into the aircraft structure through the use of replaceable components.
- Category III - Utilize the inherent properties of the aircraft structure to provide energy absorption capability.

The structural elements, operational features, and limitations of the individual cargo restraint systems within these three categories will be described in this section. Several restraint systems were eliminated, after initial consideration (and will not be further described), for the following reasons:

1. High friction packaging was eliminated due to its dependence on gravity and its incompatibility with all flight maneuvers.
2. A vacuum air cushion system involving perforated plates was rejected because of environmental conditions and dirt.
3. A mechanical load retention system (using "ice" tongs, for example) was rejected because of weight and lack of flexibility for a variety of cargo.
4. Inflatables deployed as crash sensors were rejected because of expected complications of deployment mechanisms and sensor development, particularly since direction of crash would be unpredictable.

5.1 CATEGORY I - LOAD ATTENUATION WITHOUT AIRCRAFT MODIFICATION

Category I systems are those designs that can be integrated or encapsulated as packaged units into an assembly (line replaceable unit) which can be added to existing equipment (straps, chains, tiedowns) or structure without aircraft modification. It is recognized that a logistics problem exists with regard to initial provisioning and later resupply of these systems, and that they are affected by usage and combat losses. Consequently, their use still depends upon the human element in the restraint system.

System 1

System 1 utilizes the Chinook (CH-47) cabin floor with a 20-inch-square grid pattern consisting of eighty-seven 5K static capacity and eight 10K static capacity tiedown rings. (See Figure 96.) Thirty-two MC-1 or CGU-1A ratchet buckle strap assemblies of 5K capacity and eight MB-1 chain assemblies with a toggle type tension device of 10K capacity are furnished as GFE flyaway equipment.

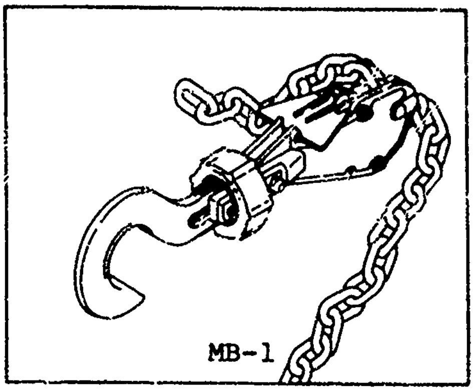
The limitations of System 1 are in its static strength characteristics and crash load attenuation capacity, and in its lack of quick-tiedown and -release capability. In addition, the 5K capacity straps are excessively long and there are no designated stowage provisions; consequently, they may be lost or unavailable at the time they are needed.

The Chinook cargo restraint system was designed in 1958. Although it has no significant inherent capability of absorbing the crash pulse energy (References 1 and 2), it will be included in the evaluation as representative of objective tiedown practice typical of current aircraft throughout the world. In this respect, it will be useful as a frame of reference for the evaluation of systems specifically designed within a required crash load limitation.

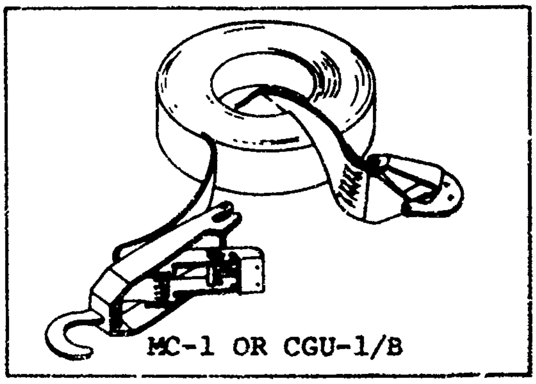
System 2

System 2 consists of load limiting cargo restraints of 5K and 10K capacity, using AAE-developed wire-bending devices. It also includes the use of the Chinook floor tiedown ring matrix and Aeroquip multipoint vehicle tiedown assemblies which include a quick-release feature (Figure 97). The load-limiter strap assemblies, while quick attaching, do not include quick-release features. Wire-bending load limiters are of 5K and 10K load limiting level.

The wire-bending concept has been given some laboratory testing by the manufacturer and USAAVLABS, but has not been given a field evaluation to date.



10K CAPACITY



5K CAPACITY

TIEDOWN DEVICES

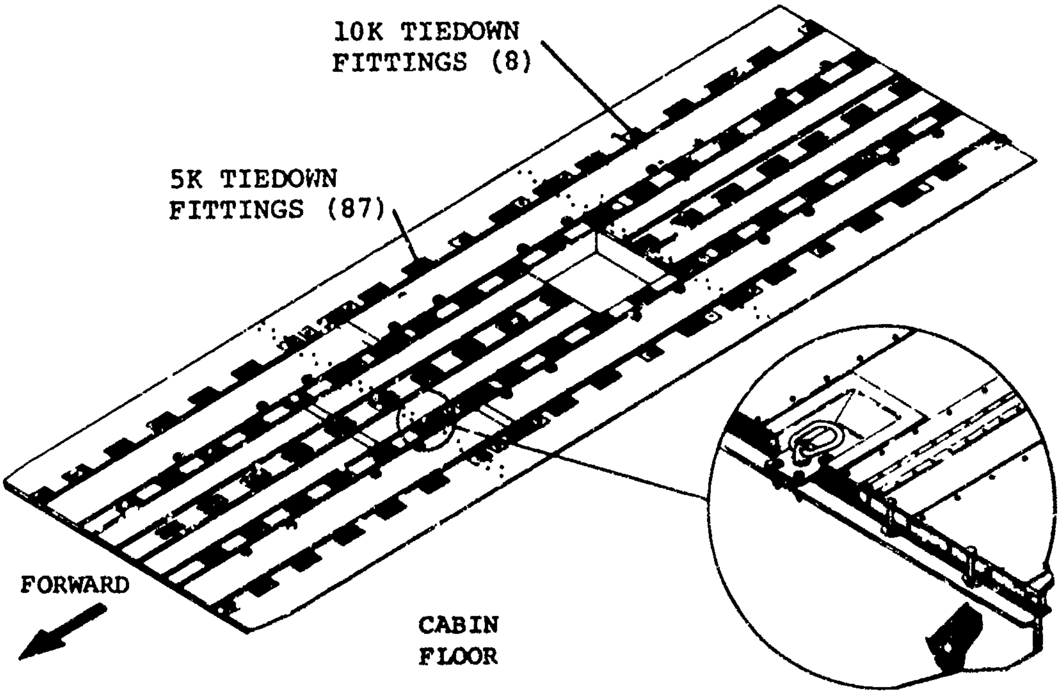


Figure 96. System 1 - CH-47 Restraint System.

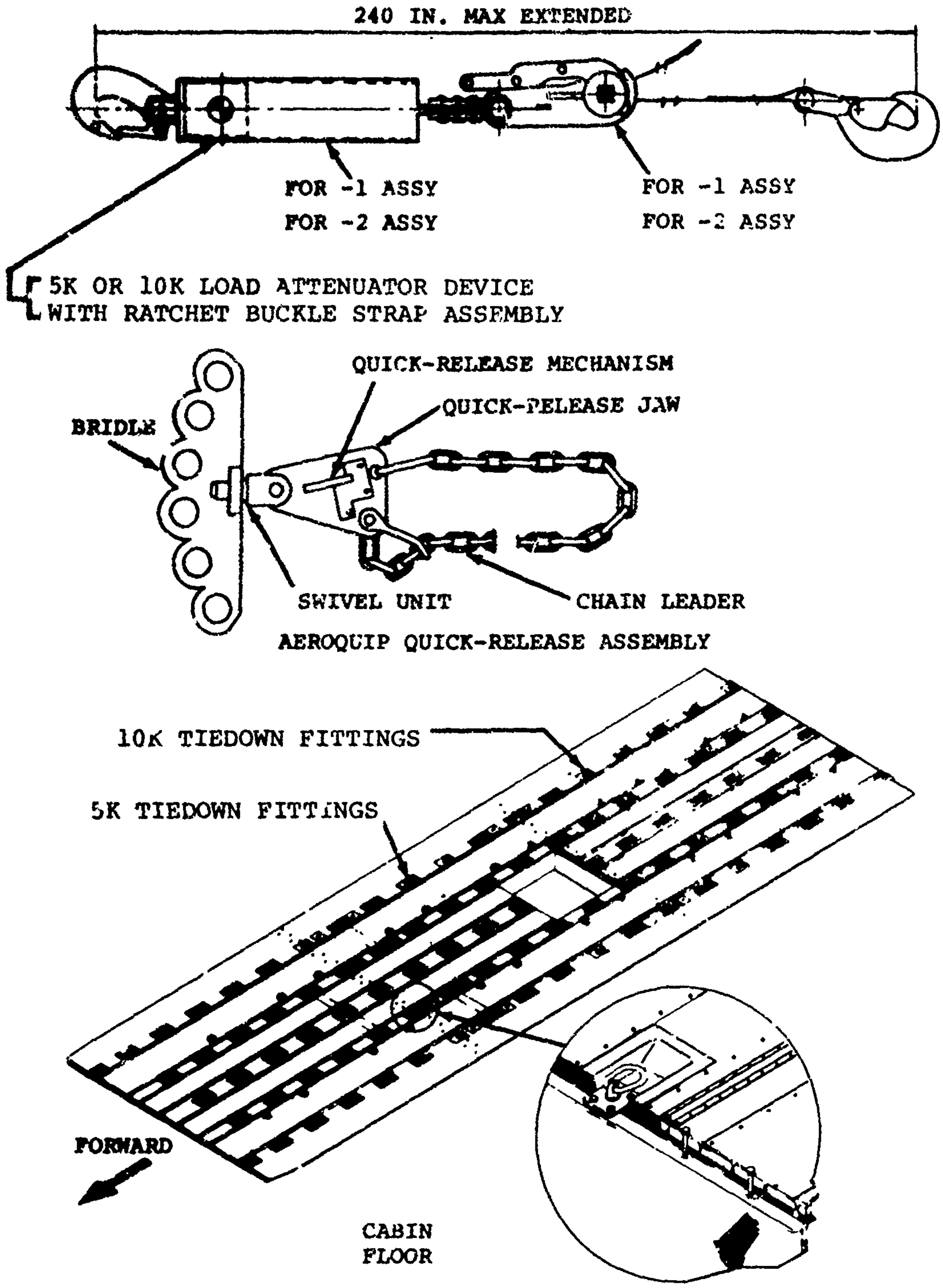


Figure 97. System 2 - Load-Limiting Cargo Restraint System Utilizing USAAVLABS/AAE Developed Wire-Bending Devices.

By contract direction, System 2 will be the baseline by which all other systems will be compared.

This system does not provide for stowage of restraint straps and quick-release assemblies; they are therefore subject to frequent loss and unavailability and can cause injury to personnel.

System 3

System 3 (Figure 98) consists of the basic elements of System 2, with the incorporation of quick-release ratchet buckle assemblies and the addition of throwover nets incorporating quick-tiedown and -release fasteners. Load-limiters are also incorporated.

Use of the AAE-developed load attenuating straps and incorporation of a quick-release feature at one end would greatly improve the cargo release phase of cargo handling during current combat operations. Reducing time to release cargo in a combat landing zone also reduces exposure to enemy fire, and should psychologically induce the crew chief or cargo master to use equipment available for proper cargo tiedown.

The use of throwover nets with load attenuating quick-release straps would control small-sized, lightweight (Class A) cargo, thereby controlling potentially lethal objects in the event of emergency or crash landings.

As an alternate development, a dual-purpose seat webbing/cargo net should be evaluated. This dual-purpose net (as shown in the illustration) would always be available in the aircraft, would incorporate load attenuation, and would reduce the equipment storage problems that now exist.

Since efficiency requires using the load-limiter net for Class A cargo and the load-limiting straps for Class B cargo, one limitation of this system would be the possibility of incorrect use for either type cargo.

System 4

System 4 (Figure 99) consists of System 1 plus the use of load-limiting barriers, with provisions for quick tiedown and release, and storage for the barriers.

Commercial cargo-type barrier nets incorporating load attenuating mechanisms at structure attaching points are employed to restrain cargo in the event of a crash. The net would be erected or stowed in a manner similar to commercial cargo aircraft. Vehicles and cargo would be compartmented or

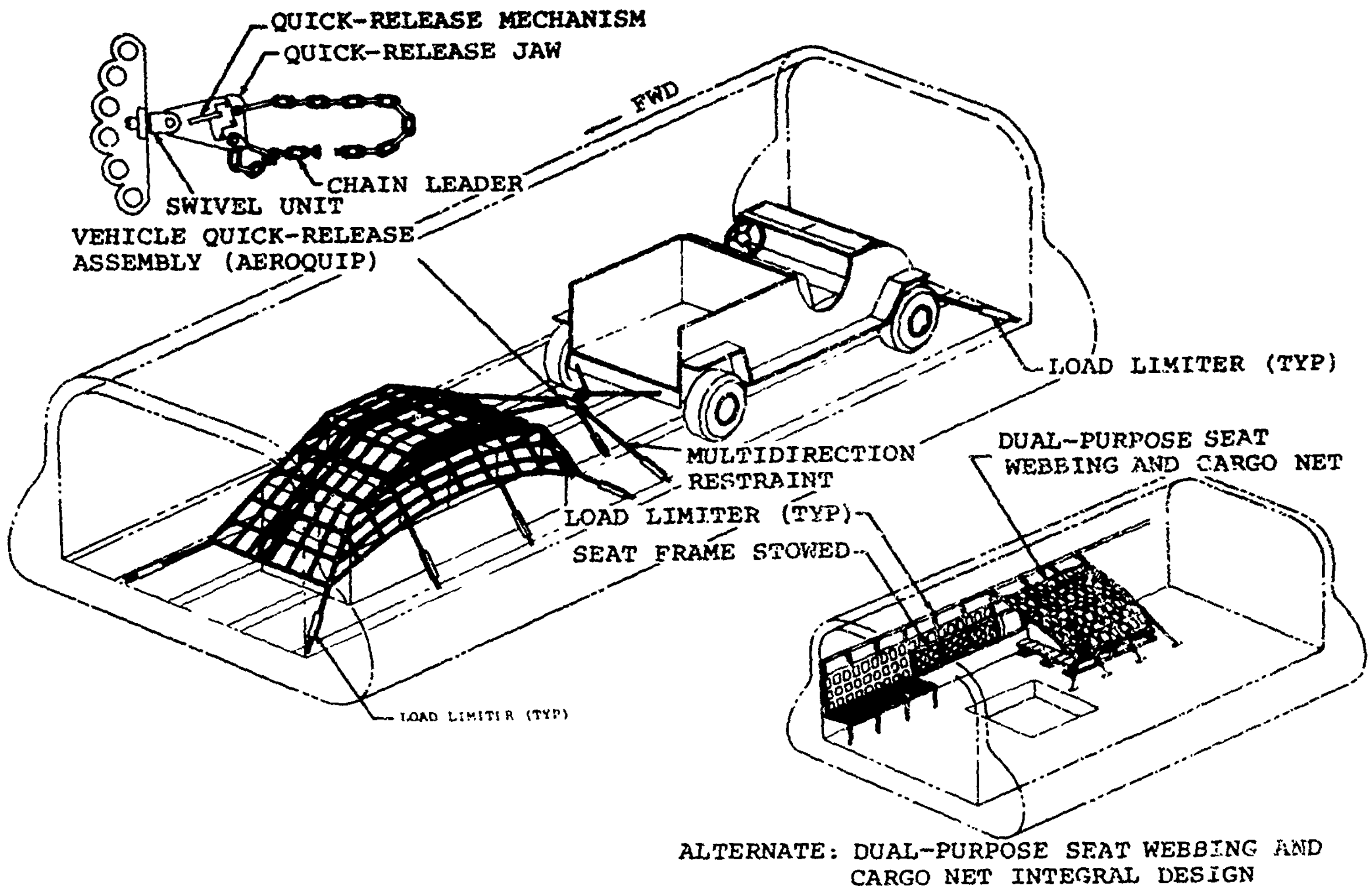


Figure 98. System 3 - System 2 Plus Quick Release (for Class B Cargo) and Throwover Nets Incorporating Load-Limiters and Quick Tiedown and Release.

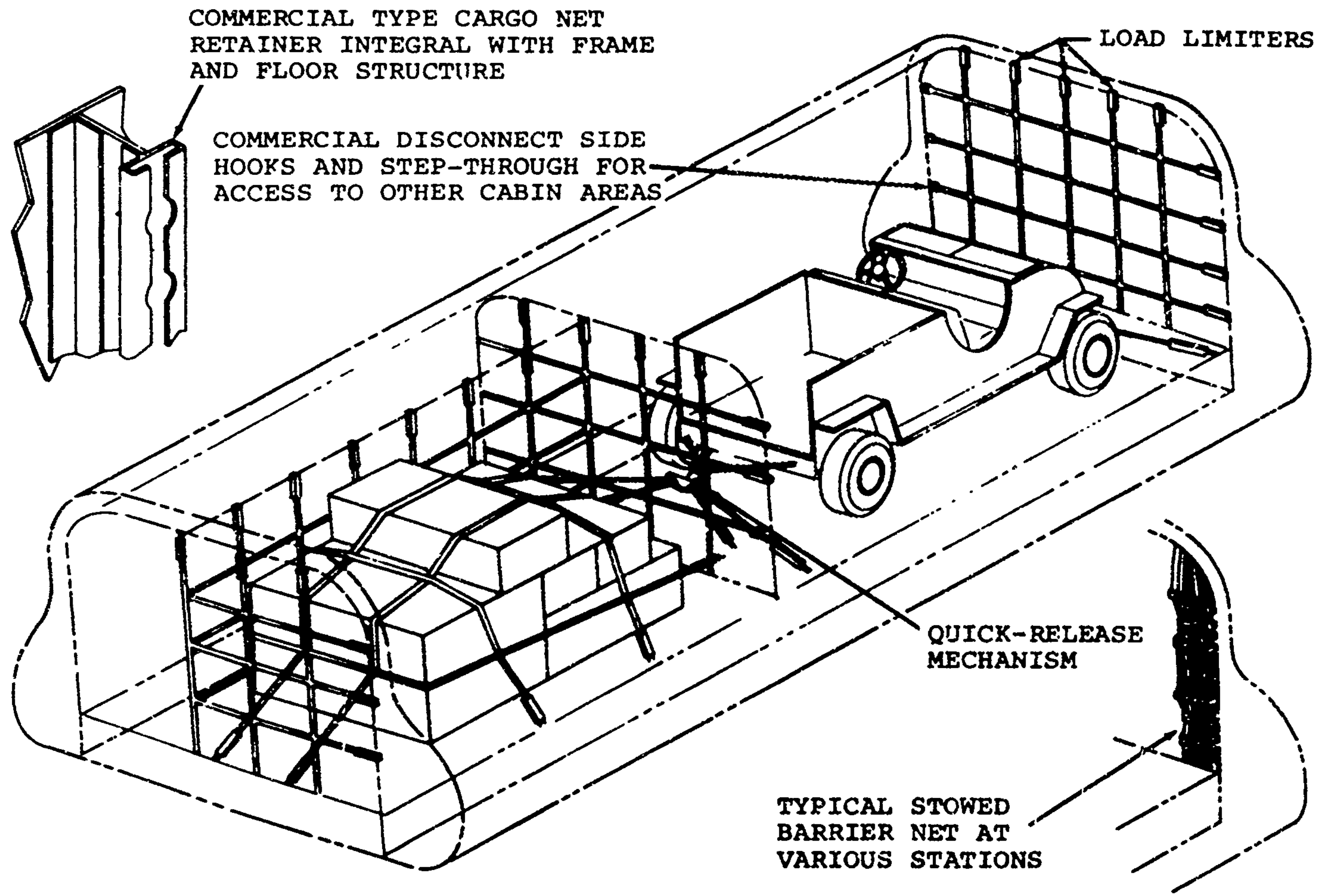


Figure 99. System 4 - System 1 Plus Load-Limiting Barrier, With Quick-Tiedown and -Release Stowage Provisions.

separated from passengers and would be specifically restrained for flight loads only.

System 5

Inflatable load attenuators (combining Systems 2 and 4) supplemented with nets and barriers form System 5.

System 5, as shown in Figure 100, uses barrier nets, throwover nets, and load attenuating inflatable bags to fill the voids between nets and cargo and/or vehicles, thereby preloading the restraint. The cargo and vehicles are quickly loaded, and deflated bags are blown up to eliminate any looseness between cargo and nets or vehicle and nets. Pressure regulating bleed valves regulate the inflation pressure and also control cushioning of cargo and people in the event of a hard landing or crash.

The use of inflatables to isolate or separate cargo has greatly reduced costs in railroad and truck shipping, thereby greatly decreasing rigid bracing requirements during shipping.

Inflatables, as described in this concept, are expected to be quite popular and should find many additional uses. It is conceivable that maintaining a supply aboard the aircraft for continued availability and cargo handling could be difficult. Advantages are expected to be low cost and expendability. (Nondisposable inflatables are also available, but at approximately 10 times the cost.)

System 6

System 6 uses the standard U.S. Army 40- x 48-inch wooden pallet and barrier nets with quick loading roller assemblies, as shown in Figure 101.

For this study it is assumed that the system would use a roller conveyor system on the aircraft floor and ramp, with commercial type barrier nets incorporating load attenuating devices. The roller assemblies would incorporate a pallet locking device to restrain the pallet in all directions. The Army wooden pallet would be supplemented by a pallet adapter which would permit the pallet to be locked to the roller conveyors and then to the cabin floor. Cargo would be secured to the pallets with throwover nets capable of restraining flight loads, while the barrier nets would confine the cargo in the event of a crash. Again, the barrier nets would be easily and quickly rigged or stowed.

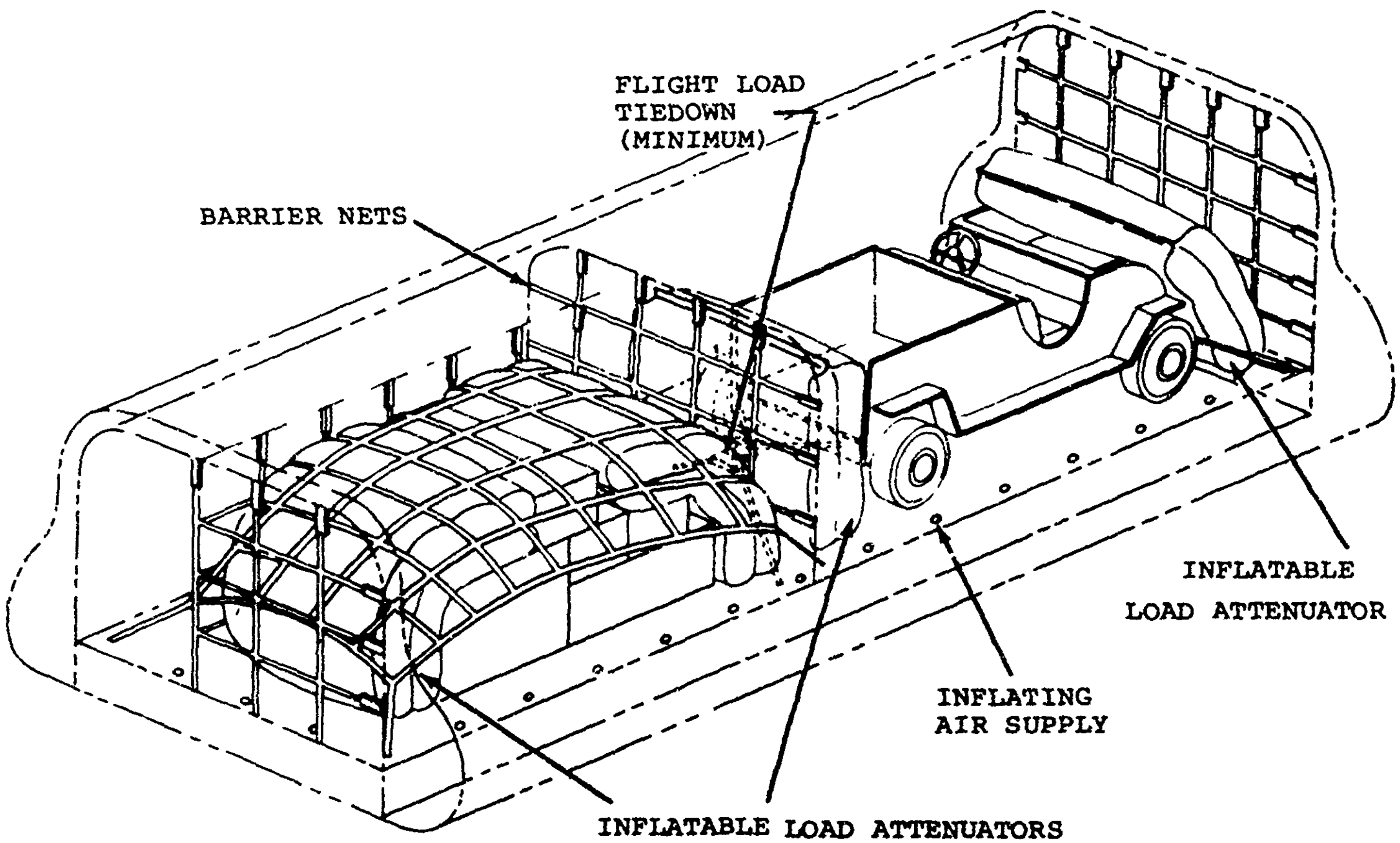


Figure 100. System 5 - Inflatable Load Attenuators Plus a Net and Barrier System.

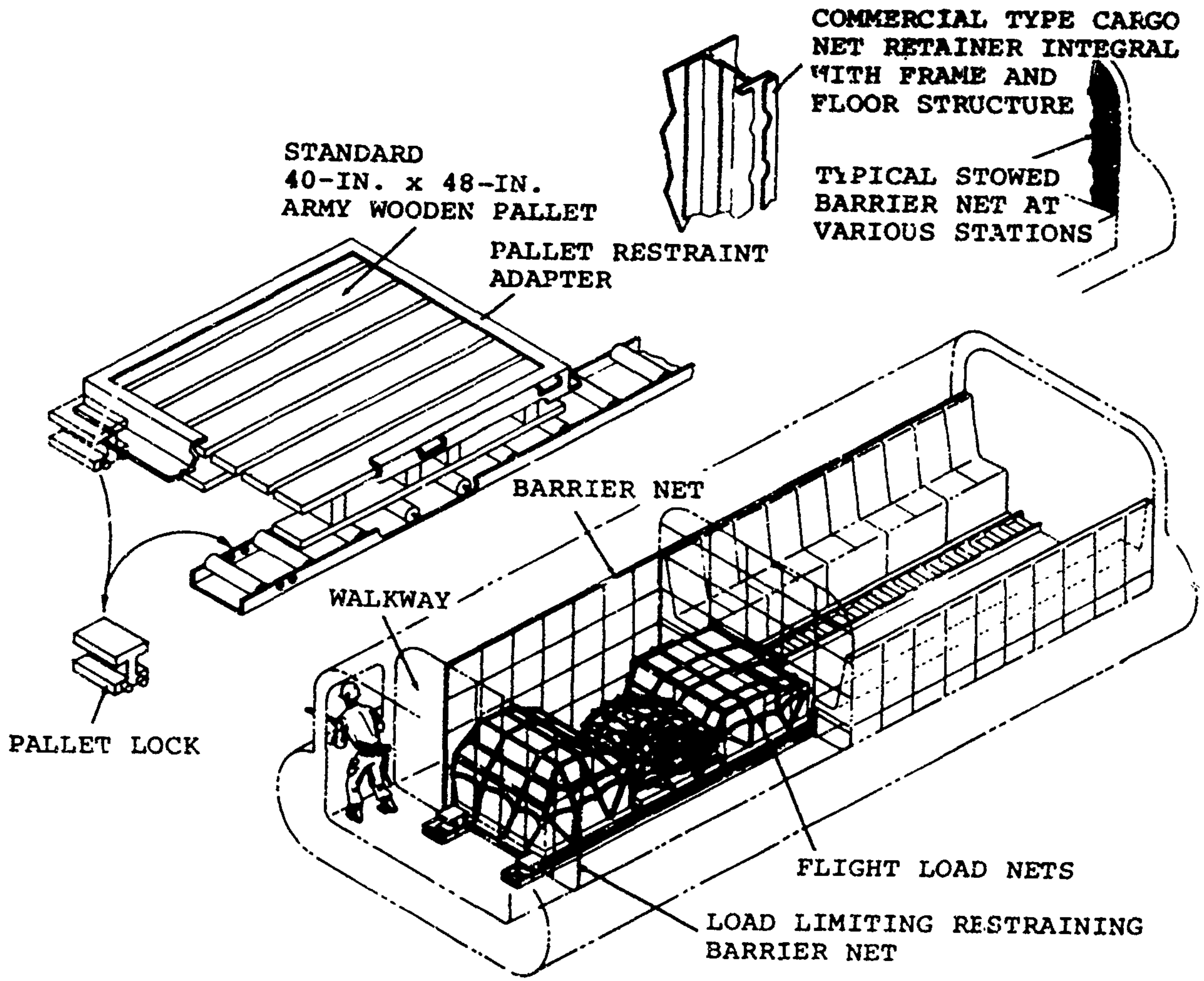


Figure 101. System 6 - Rail Restraint System for Prepalletized Cargo (Commercial Adaptation).

5.2 CATEGORY II - LOAD ATTENUATORS INCORPORATED IN AIRCRAFT

The second group of concepts would substitute built-in load attenuation devices for existing tiedown fittings, and may contain self-storing features for the restraint devices. Category II integrates the majority of the Category I concepts into the airframe structure as a replaceable component (i.e., replacement of a tiedown fitting with a stroking energy-absorbing packaged device which incorporates a tiedown capability).

System 7

This concept would substitute a load attenuating device for existing tiedown rings. These energy absorbing devices would be supplemented by strap assemblies incorporating quick-release and ratchet takeup features for general cargo tiedown. For vehicle tiedown, 10K multiple attachment quick-release assemblies would supplement the tiedown configuration. Figure 102 illustrates System 7.

System 8

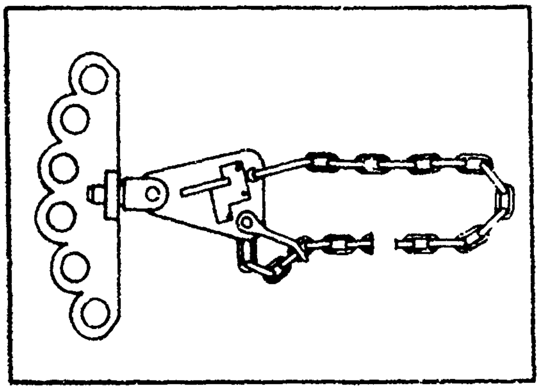
System 8 is an integral self-storing, quick-tiedown and -release strap concept, as shown in Figure 103. Again, with minimum rework, the existing tiedown fittings are replaced with a unitized assembly which integrates a packaged energy absorbing device, combined with a locking reel and an automatic tensioning feature, capable of self-storage of the cargo tiedown strap. The strap would terminate with a quick-release hook assembly for multiple-purpose cargo tiedown, to secure miscellaneous cargo and cargo nets or to restrain vehicles.

System 9

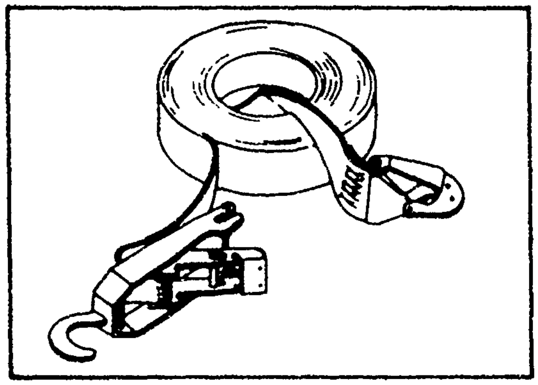
System 9 is basically System 7 supplemented with self-stowing sidewall nets and a multilocation barrier (see Figure 104). In addition to the equipment described in System 7, System 9 uses self-storing cargo nets featuring a quick-release capability for securing cargo for flight loads. The nets are self-storing under existing troop seat locations and can be joined together to suit variable length loads.

To provide passenger and crew protection in the event of a crash, the cabin would be compartmented with the use of energy absorbing barrier nets which would be quickly stowable, similar to those described in previous systems.

An alternate concept which could be integrated into the system is the interconnection of the tiedown fittings with attenuating cable, thereby effectively increasing load attenuating capacity when needed, as shown in Figure 105.



10K QUICK-RELEASE
ASSEMBLY (AEROQUIP)



10K CAPACITY LOW ELASTIC
STRAP ASSEMBLY WITH
QUICK-RELEASE RATCHET

TIEDOWN DEVICE

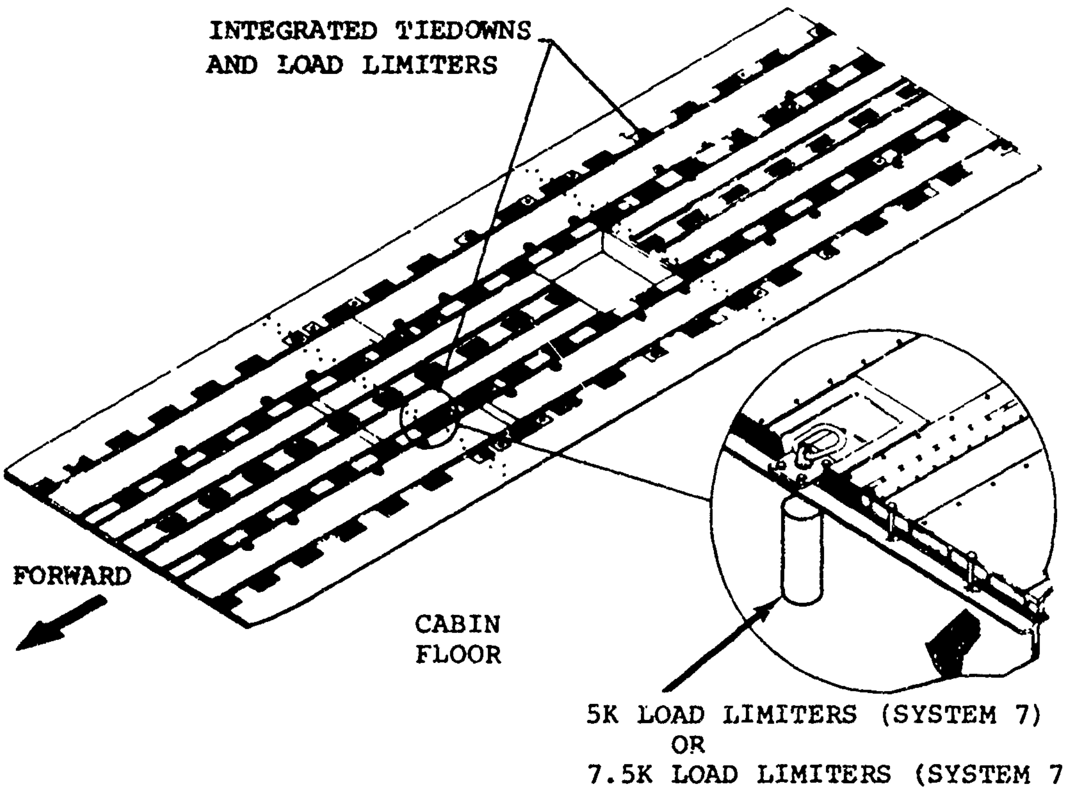


Figure 102. System 7 - CH-47 Restraint System Incorporating Integrated Under-the-Floor Load Limiters.

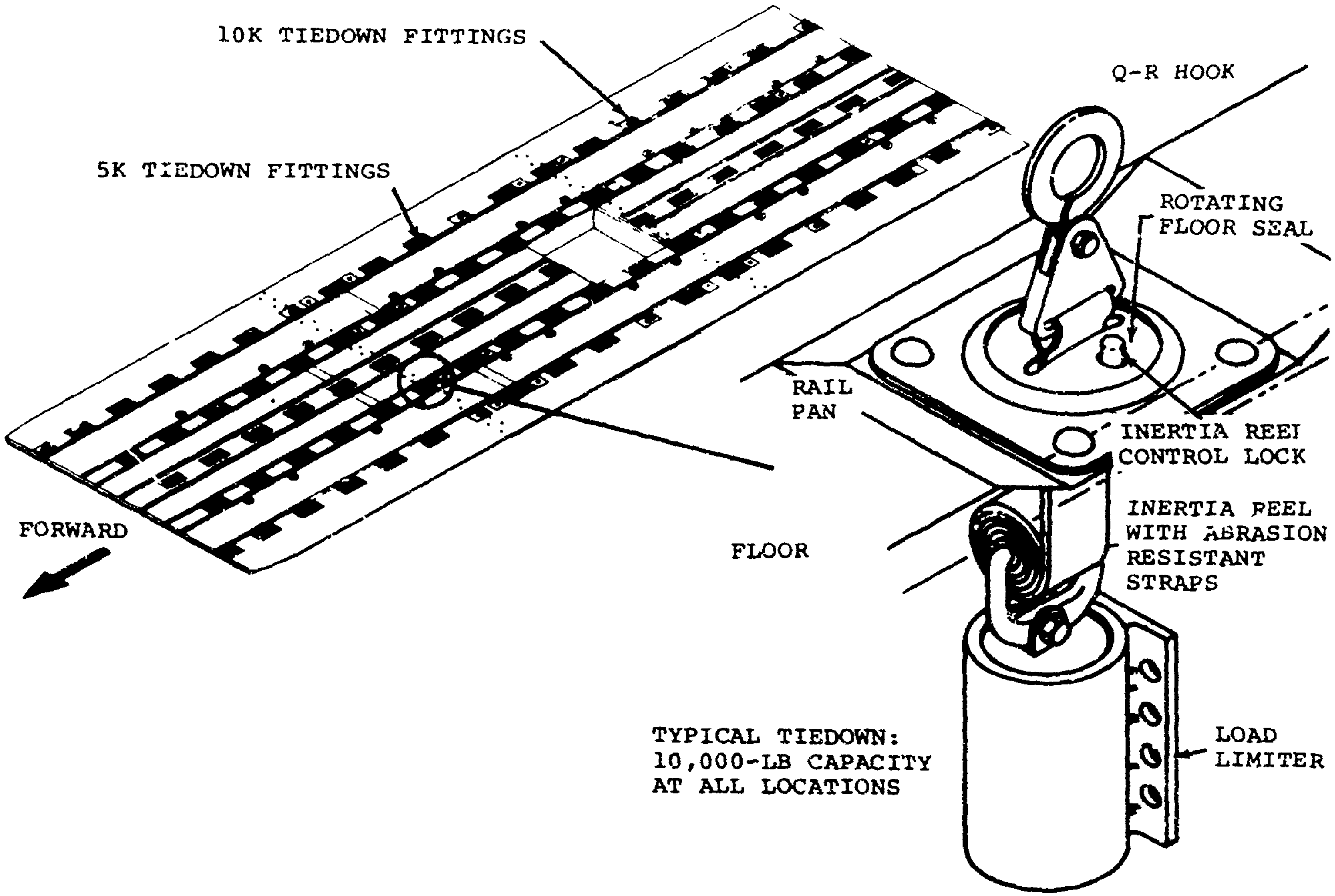


Figure 103. System 8 - Integral Self-Storing Quick-Tiedown and -Release Strap with Load Limiter.

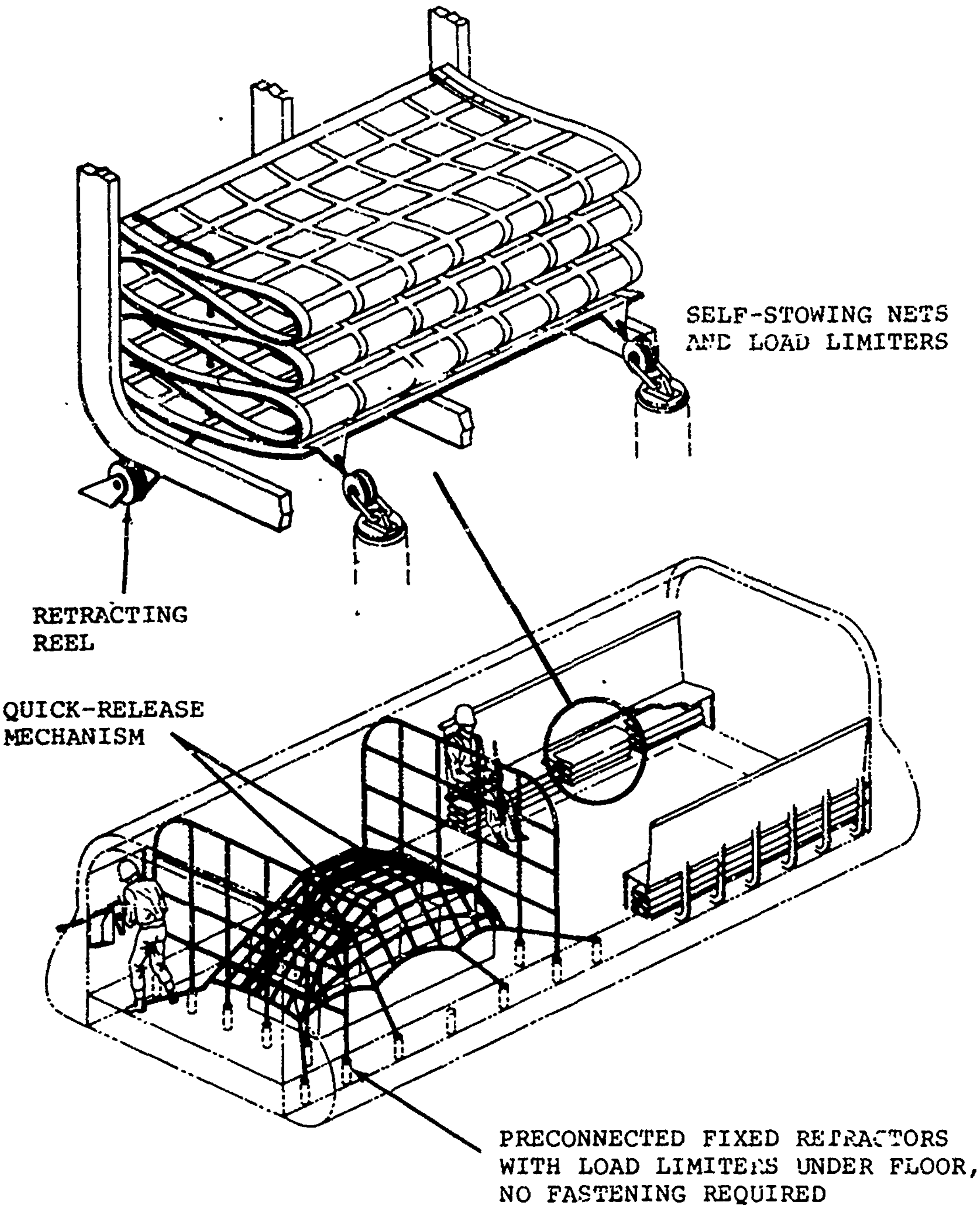


Figure 104. System 9 - System 7 with Self-Stowing Sidewall Nets and Multilocation "Shower Curtain" Barrier.

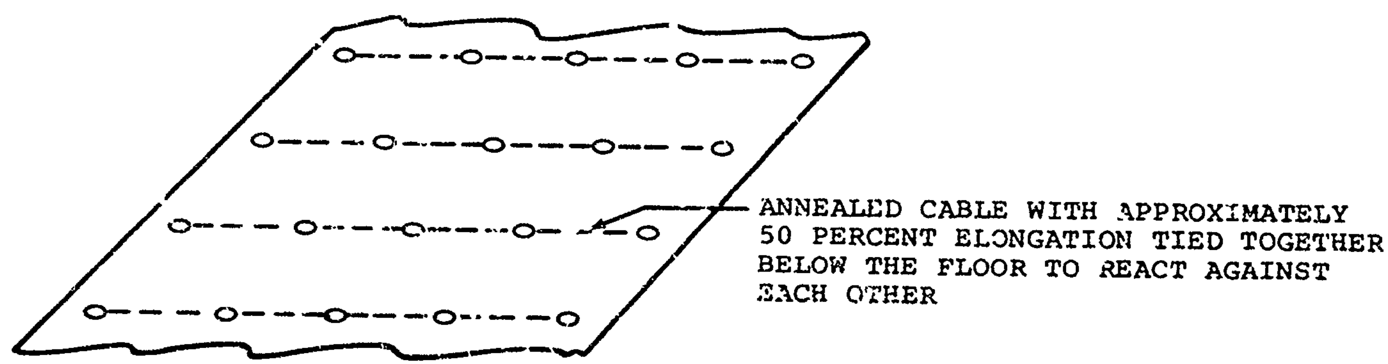


Figure 105. Alternate System 9A.

5.3 CATEGORY III - ENERGY ABSORBING AIRFRAME STRUCTURE

The third category of concepts being considered includes those using airframe structural deformation under crash loads to restrain cargo in a controlled manner. Short stroke cargo load attenuators are used to retain the load while the primary structural deformation absorbs the major portion of the crash pulse energy. These concepts can be adapted in varying degrees to existing helicopters and future aircraft designs.

To a great extent, this approach will reduce onboard stowage of loose tiedown equipment of the types now in general use. Design features that would inadvertently load the airframe in a noncrash situation should be avoided, as they cause hidden or costly damage to the airframe. A typical example would be where a truck is driven off before all the tiedowns are disconnected, thus putting a substantial shock load on one or two remaining tiedown links and initiating the planned energy absorbing action of the associated airframe element. This could result in major aircraft damage and subsequent costly repair, or even a major accident if undetected. Therefore, fail-safe features are required.

In contrast, a built-in load limiting device, if stroked in this manner, could simply be replaced or reset.

Both Category II and III designs would reduce the logistics resupply problems, and, additionally, reduce the human element associated with logistics and proper cargo restraint.

The complexity of these designs would require considerable analytical work and possible computer study. In addition, the complexity of some of the concepts may require a test of fuselage sections, wherein a load would be secured in a specific manner and drop tested for determining the response of the aircraft structure to the load.

System 10

System 10 utilizes existing tiedown fittings secured to the floor frames with tension rods. The floor frames have energy absorbing inserts of honeycomb material, compatible with the flight design shear loads, but which, in the event of a crash, would be capable of being crushed as the tiedown fitting is pulled from the floor (as shown in Figure 106).

System 11

This design concept uses additional structural members attached to the relatively softer parts of the fuselage structure between frames. Structural deformation is induced during crash impact of cargo against the barrier nets attaching to these additional

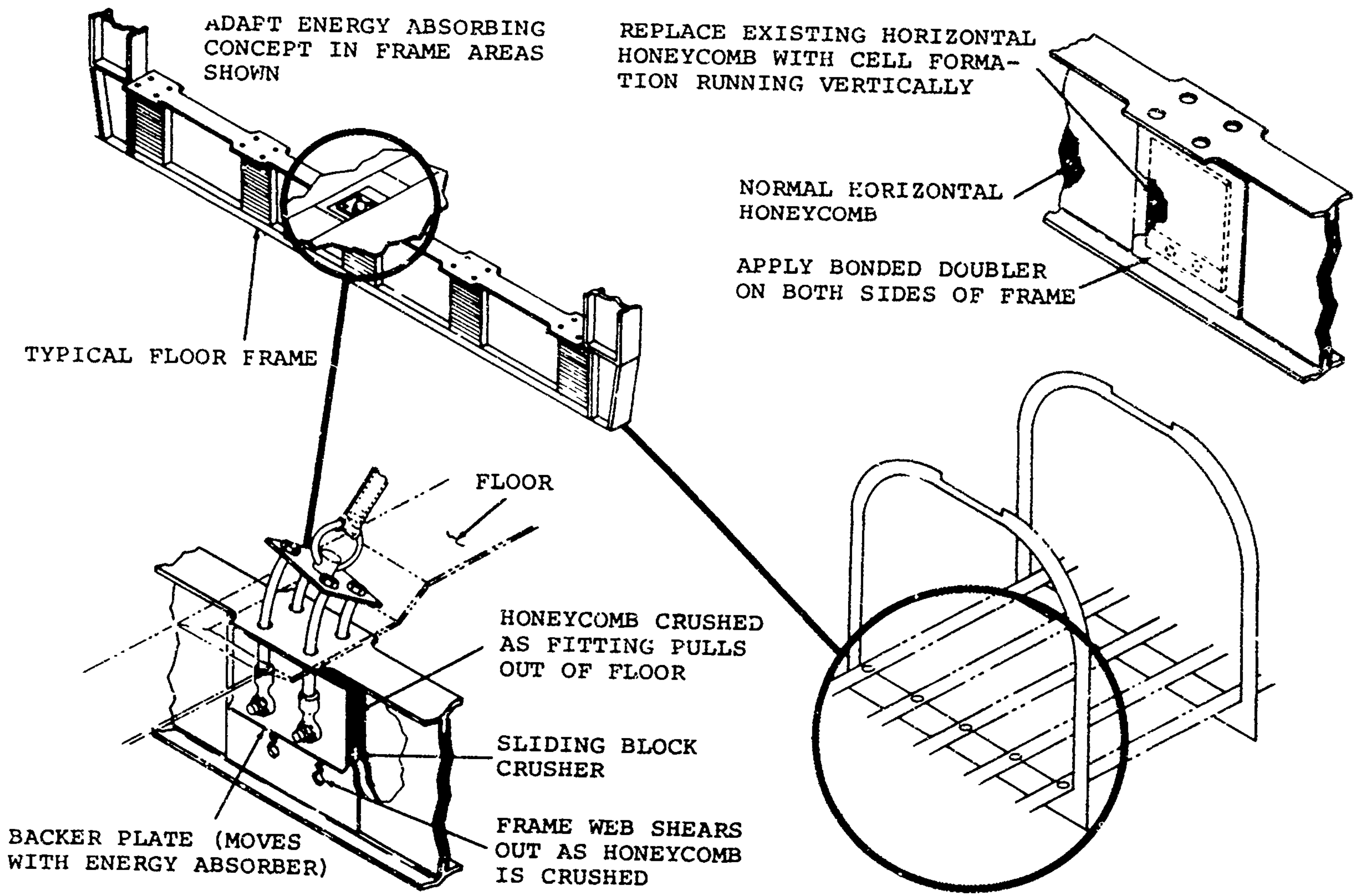


Figure 106. System 10 - Frame Deformation for Integral Helicopter Cargo Restraint.

structural members. Analysis of this type of structural modification will undoubtedly require a computer study. In this concept, similar soft attachments would be required in the floor design.

Net storage would be similar to that shown in previous concepts. The barrier nets would contain rings at various locations to permit the attachment of a variety of vehicles, packages, or palletized loads. Figure 107 illustrates the System 11 concept.

System 12

System 12 (Figure 108) utilizes a dual-sided frame construction with an entrained member (stroking unit) sandwiched between them. This energy absorbing frame assembly has multiple attachment points for the load. The 'frame' side plates surround a center member incorporating a bulb-like section which, under load, pulls inward, causing distortion of the two outer sidewalls of the frame. These frames would be integrated with the sidewalls and overhead area, and would flex or bend as an assembly in the direction of the load.

System 13

System 13 (Figure 109) uses the subfloor structures for load attenuation. This system includes channel sections attaching to the floor frames. The channels envelop (or clip over) the floor beam extruded tee sections and cause bending of the beam tee as a function of the floor upward displacement; or they bow when the tiedown fittings yield, or when a fused section fails.

System 14

System 14 uses inflatable dunnage bags integrated into the overhead structure. As required, portions of the system would be inflated to restrain various mixed cargo loads, as shown in Figure 110. An automatic push-button inflation system could be utilized to inflate the bags, after positioning of cargo or vehicles.

By reversing the system operation, the air from the bags could be exhausted, and the bags could be retracted into their respective storage areas. Where necessary, the bags would be supplemented with barrier nets to reinforce them and/or provide a barrier between cargo and passengers. This concept will require some design study and development tests before an operational system can be perfected.

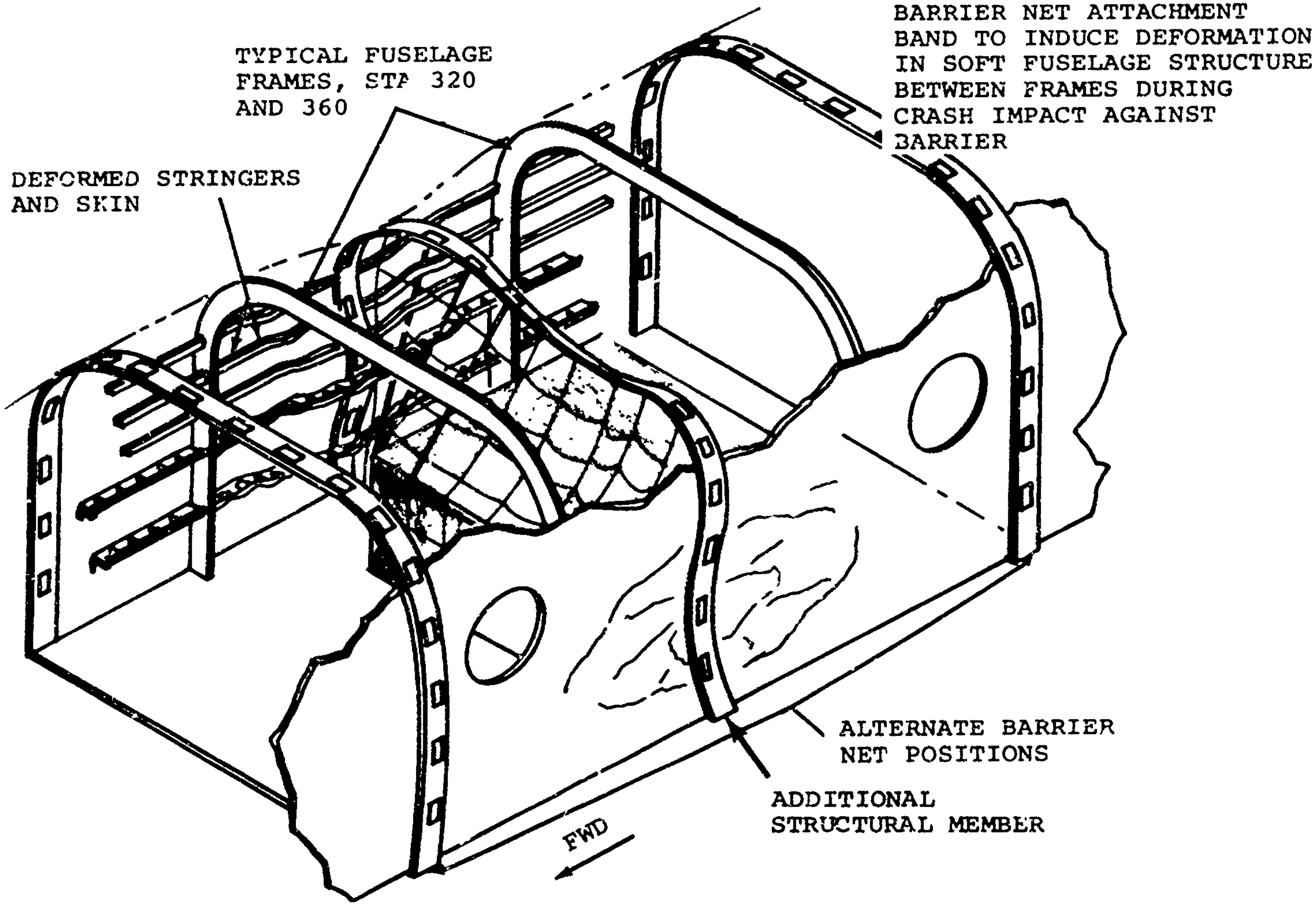
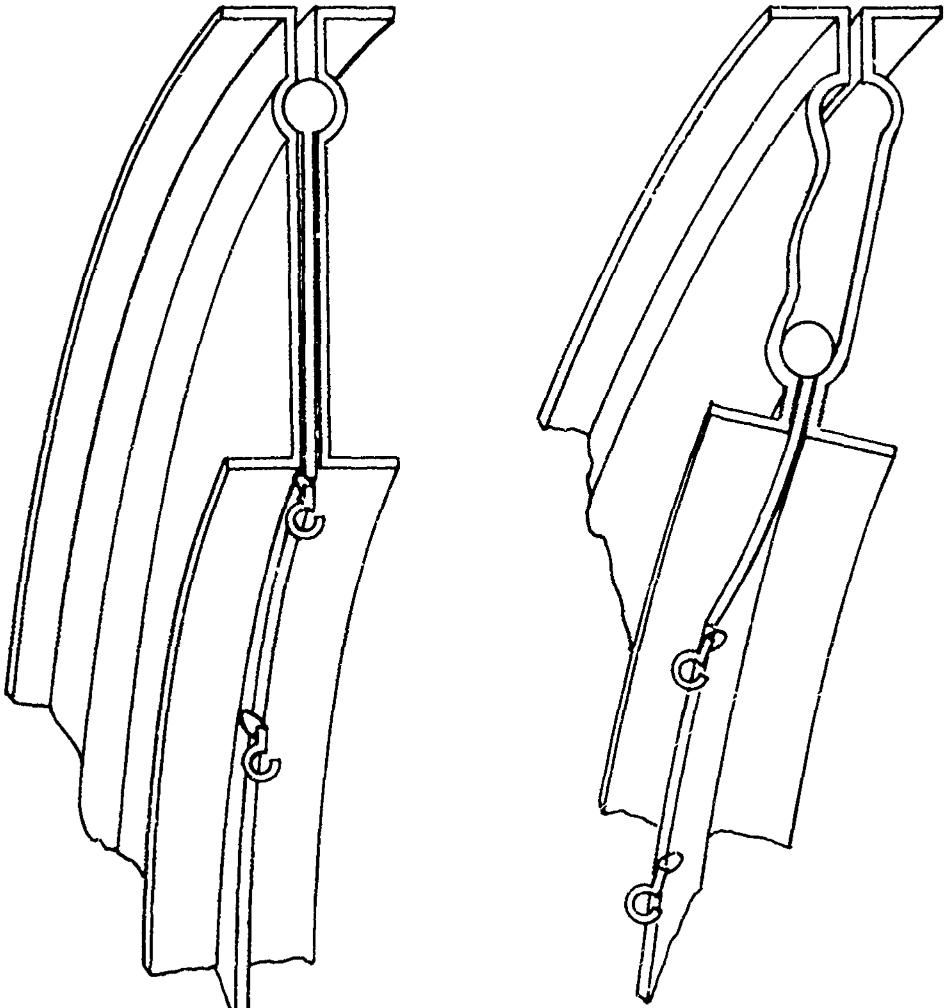


Figure 107. System 11 - Fuselage Deformation for Integral Helicopter Cargo Restraint.



TYPICAL FRAME CONSTRUCTION

AFTER DEFORMATION

Figure 108. System 12 - Dual-Sided Frame Construction with Entrained Member (Stroking Unit) Sandwiched Between Frame.

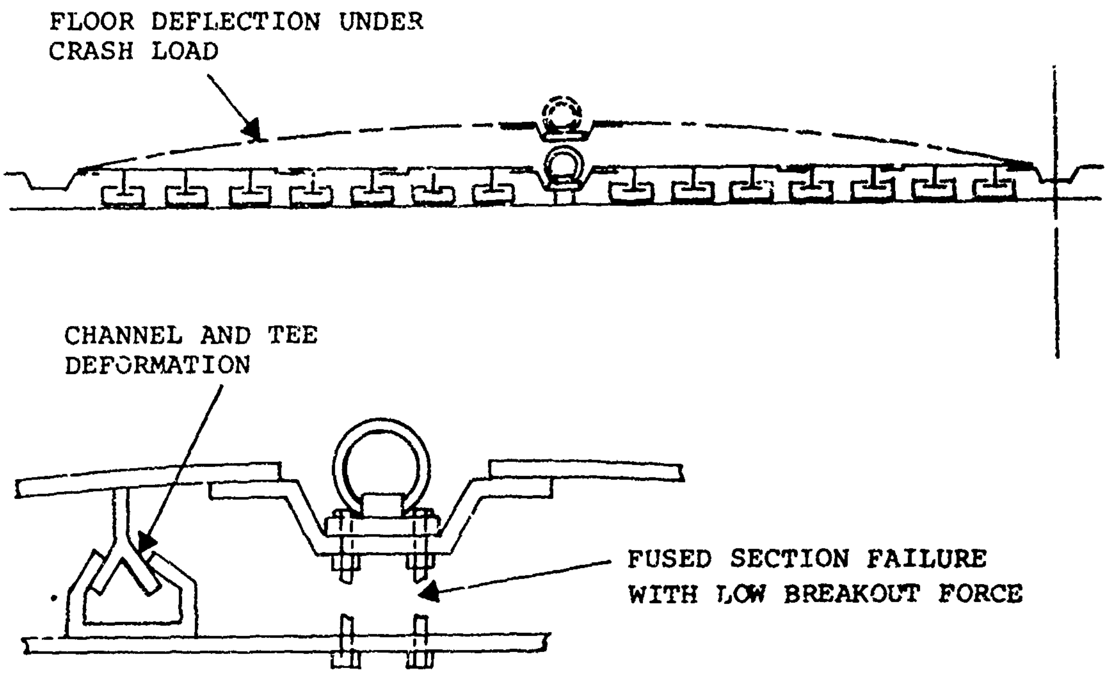


Figure 109. System 13 - Subfloor Structures for Load Attenuation.

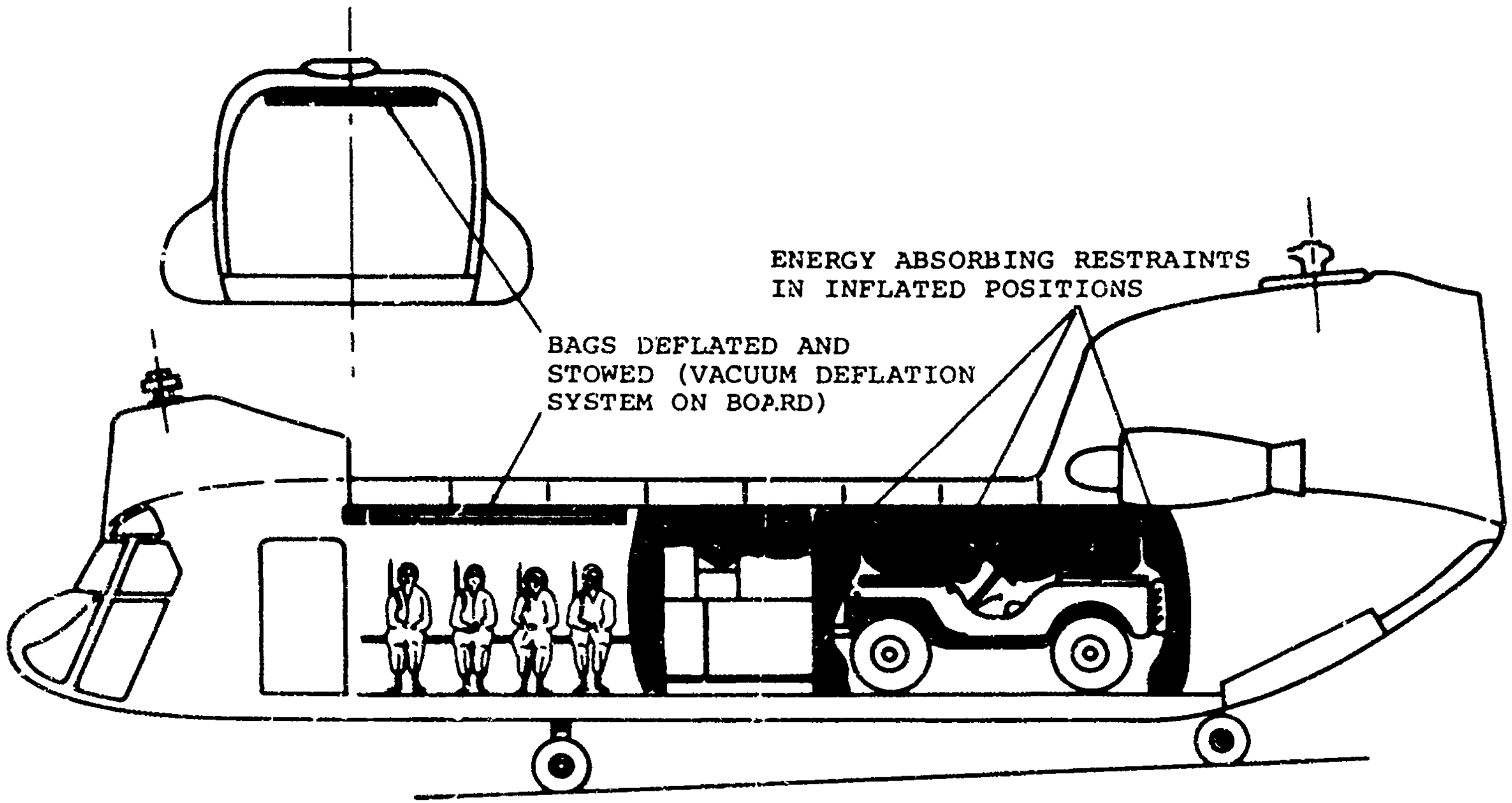


Figure 110. System 14 - Fully Integrated Inflatable Restraint System Using Push-Button Control for Deployment and Stowage.

6. SYSTEM ANALYSIS AND SELECTION

This section contains an analysis of the candidate cargo restraint systems and energy absorbers (previously defined in Section 5) according to the pertinent qualitative factors predicated on the basic design objectives described in Section 3. This analysis will result in the selection of a feasible cargo restraint system to be further subjected to a quantitative trade-off study with existing restraint methods. The trade-off methodology is developed and utilized in Section 7.

Boeing's continuing close association with the U.S. Army and the environmental problems it has experienced in the use of the CH-47 in Vietnam has borne out the importance of qualitative factors in a cargo restraint system. Pertinent findings are documented in Section 2.1, SECURING INTERNAL LOADS, and in Appendix I, DESCRIPTION OF INTERNAL CARGO HANDLING IN VIETNAM.

The findings of a Boeing engineering review team, sent to RVN for a review of Chinook operations, further reinforced the overbearing nature of the qualitative factors, as well as the need for "simple" solutions to the cargo restraint problem. Comments by the Vietnam survey team on internal cargo restraint and safety are documented in Appendix V.

From this background, the qualitative factors will play a major part in the consideration and selection of the cargo restraint system to be selected for the trade-off study.

6.1 QUALITATIVE FACTORS

The nine design objectives defined in Section 3 are presented below to describe their qualitative aspects in a more detailed manner.

The qualitative factors are presented in order of importance, with the survivability objective given the highest priority, followed by crashworthiness and redundancy. These latter objectives are considered of equal value because they are characteristics of the system integrity necessary to provide high survivability levels. Consequently, for the restraint system to function properly, the qualities of crashworthiness and redundancy must have congruity.

A. Survivability

A restraint system shall possess the capability of restraining a piece of cargo to a g level associated with the 90th percentile level of survivability. It shall also be capable of retaining the cargo in all directions (forward, aft, lateral and vertical).

B. Crashworthiness

Crashworthiness, as defined here, assumes a crash in any aircraft attitude. The restraint system must then retain cargo through both primary and secondary impacts.

Various degrees of crashworthiness may exist; for example:

1. Cargo breaks free; restraint system not functioning.
2. Damage to system raises g level but system continues to function.
3. System is distorted with only mild g level change; system functions satisfactorily.
4. No system damage; system functions satisfactorily.

C. Redundancy

Assuming a crash in any direction, the cargo restraint system having redundancy shall not lose restraint effectiveness by virtue of rupture of any of its components. This shall apply to primary and secondary crashes, or skewed loads.

D. Safety

Safety is considered the next ranked item although in weighting it is considered of equal importance to minimum tiedown and rapid rigging because these items are tremendously important in the combat environment.

Each of the systems considered shall have the following characteristics:

1. The system shall in no way interfere with flight safety involved in normal takeoff, flight, or landing.
2. The system shall not impede egress on landing or loading (considering the standard system as a baseline of egress capability).
3. The system shall in no way permit shifting of cargo position with changing aircraft attitude (in any direction).
4. Use of the system shall not encourage laxity or omission due to hastily applied restraints or apparent false security.
5. Cargo displacement from primary or secondary impulses shall not cause injury while restraining the cargo.
6. The system shall be fail-safe, and no loose parts shall strike occupants of the aircraft.
7. The system shall provide some warning of either improper installation or inadvertent actuation.

E. Minimum Tiedown

This objective relates to the interface between the individual piece of cargo and the restraint system with respect to the anticipated dynamic loading conditions. The following conditions may be considered applicable:

1. No restraint provided.
2. Light restraint for flight loads only.
3. Restraint for a combination of flight and crash loads (use of barrier for forward or aft crash loads).
4. Tiedowns combined to provide partial restraint in all directions.
5. Individual restraint to provide for maximum crash loads in all directions.

F. Rapid Rigging

Rapid rigging is defined as the time to lash-up and release the individual cargo item. The system shall in no way defeat the purpose of encouraging early release prior to landing (for crew acceptance). It shall also provide for the needs of a hostile environment by being equally compatible to the CONUS or combat situations. The functional restraint operation consists of the following components (Reference 10):

1. Position to restraint
2. Attach the restraint
3. Tension to restraint
4. Lock the restraint

If quick-release equipment is employed, the functions of release of the cargo, while executed in reverse, need not necessarily be followed. In this case only one operation is needed (devices are stowed after cargo is unloaded).

The time required to restrain cargo will depend upon whether:

1. The cargo is restrained manually at individual tiedown points with single straps (chains are excluded).
2. Double straps or grouped tiedowns are used.
3. Manual tensioning of the tiedown is used.
4. Semiautomatic or ganged lash-up tensioning and release is used.
5. Completely automatic lash-up tensioning and release is used.

Flexibility of the system to adapt to the widest variety of cargo is required. Under this term the various degrees of acceptability are as follows:

1. Class A cargo only
2. Class B cargo only
3. Both Class A and B cargo
4. Other cargo

Human engineering shall include a minimum learning time for ease of handling of each system.

G. Sturdiness

Sturdiness is defined as the ability to handle abuses inherent in the cargo handling environment and is closely related to the basic ruggedness and reliability requirement of airborne equipment (at a minimum weight).

This is to be evaluated by the following characteristics:

1. Loss of function and availability due to damage by cargo movement, dropping of hardware, or abrasion.
2. Environmental degradation resulting in high maintenance time or parts replacements.
3. Loss of partial functioning due to environmental incompatibilities such as corrosion, temperature change, or rotting.
4. Continued function in the environment for long periods of time (passive, nonfunctioning equipment).

H. Integral Systems

The simplicity and function of an integral restraint system may vary as follows:

1. No energy absorption capacity
2. Add-on energy absorbing device (EAD)
3. Single function EAD, replaceable unit
4. Multifunction EAD, replaceable unit
5. Airframe component, dual function

Little or no maintenance shall be required. Stowability and maximum availability are requirements.

I. System Adaptability

Each system will vary in its adaptability in accordance with the following:

1. Retrofittability

   a. Add on EAD with no installation
   b. Install EAD without change
   c. Install EAD with minor modification
   d. Install EAD with major modification

e. Modify airframe component for EAD function
f. Redesign airframe for EAD function

2. New Design

a. Incorporate EAD package
b. Design aircraft component to serve EAD function

3. Mission Flexibility

a. Degrade payload by increasing empty weight or decreasing cabin size
b. Remove for special missions

4. Producibility

5. Cost

6.2 CARGO RESTRAINT SYSTEMS ANALYSIS

A detailed analysis of each system, with descriptions and comments on suitability to the nine design objectives, follows. The qualitative factors previously described are used in evaluating the candidate cargo restraint systems. For convenience, a brief description of each of the systems is repeated in its analysis.

Category I Systems 1 through 6, using add-on restraint devices, have been excluded from further development because they involve additional equipment and are subject to the same environmental disadvantages as the existing tiedown devices; mainly, the possibilities of being lost in the field or damaged by vehicles, and the requirement for stowage when not in use. Exceptions to this are: first, components common to Categories I, II, or III, such as quick-release devices and nets; and second, Systems 1 (standard) and 2 (experimental) which are evaluated as baseline systems for the trade-off study.

SYSTEM 1 (CATEGORY I)

System 1 (Figure 96) presently built into the Chinook cabin floor, is a tiedown ring matrix in a 20-inch-square grid pattern. Within this matrix there are eighty-seven 5K capacity tiedown rings in five rows along the cabin floor. In the outermost rows (buttline 44) there are eight 10K tiedown rings distributed along the length of the cabin. Cargo restraint is furnished by the GFE flyaway equipment, including MC-1 or CGU-1/A ratchet buckle assemblies. There are 32 of these 5K units. Eight 10K MB-1 chain assemblies, with toggle-type tensioning devices for use at the higher capacity tiedown rings, are also provided.

...tem 1 includes rapid tensioning tiedown devices (quick-release capability is not part of the GFE equipment). Like all systems in existence today, the combination of floor fittings and tiedown strap possesses little dynamic strength capability; nevertheless, System 1 is considered a baseline for the comparison of new systems.

Technical manuals are the fundamental source of information on number of tiedowns and restraint time for various pieces of Army cargo. Both of these factors are representative of today's tiedown practice, whether in administrative or combat use.

SYSTEM 2

System 2 consists of add-on load limiters (5K and 10K capacity) of the wire-bending type developed by AAE. These devices are used with a Dacron webbing strap (low extensible material), tensioning devices, and hook fittings. They are used in conjunction with the Chinook floor tiedown ring matrix and (in the case of vehicles) an Aeroquip multipoint vehicle tiedown assembly bridle which includes a quick-release feature.* However, individual straps do not include the quick-release features.

System 2, as shown in Figure 97, will be one of the two baseline systems used for reference in the trade-off methodology.

A. Survivability

Wire pull devices are, by design, capable of providing 90th percentile survivability; also, they function in all directions since they are in line with the straps.

B. Crashworthiness

In terms of aircraft distortion, these assemblies are unaffected by a crash. Fittings should not rupture unless load in the strap system has peaked severely.

C. Redundancy

Redundancy is not provided in this system since each unit acts independently and there are no multiple load paths.

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*Although the bridle has multiple-attachment and quick-release advantages, it also has limitations: When used for combined directional loading, the strap load capacities in a given direction are rapidly degraded as a function of their angular direction of load restraint. Since the objective of the study was to evaluate different dynamic restraint systems, the bridle, although usable, was not applied in the trade-off study in Section 7.

No advantage can be taken of structural deformation except as it may influence reduction of the impact level at the cargo floor. Redundancy (in a system using this equipment) is a function of the number of tiedowns used to the minimum number required.

D. Safety

Safety impairment is minimum. The limited information on field trials of these assemblies indicates handling to be cumbersome, which (in terms of safety) tends to discourage their usage.

E. Minimum Tiedowns

These units could meet the minimum tiedown requirements of the technical manuals for each vehicle with the 5K and 10K capacities. However, intermingling of 5K and 10K units is partly ineffective in that the units do not act in unison, and overloading of the 5K capacity strap assemblies could result.

F. Rapid Rigging

These units would be somewhat slower to use in tiedowns since they are reported to be cumbersome in handling.

The load limiter is adjacent to and much larger than the tiedown hook when compared with a plain (MC-1) strap assembly. There are advantages in that the same assemblies can be used for all types of cargo and they include tensioning buckles. The system also includes the quick-release bridle for vehicles.

G. Sturdiness

Units of this nature would be subject to severe wear and tear in the existing operating environment. (Damage incurred during testing of these units in Vietnam is shown in Figures 111, 112, and 113.) They would also suffer from being driven over by vehicles.

H. Integral Installation

Reliance for crash survivability on units that are not attached to the aircraft results in their loss and possible replacement with plain straps from which the same results may not be expected. The lack of proper stowability may result in these items becoming lethal missiles when not in use (as shown in Appendix I).

Figure 111. Experimental USAAVLABS/AAE Load-Limiter Assembly After Vietnam Use.

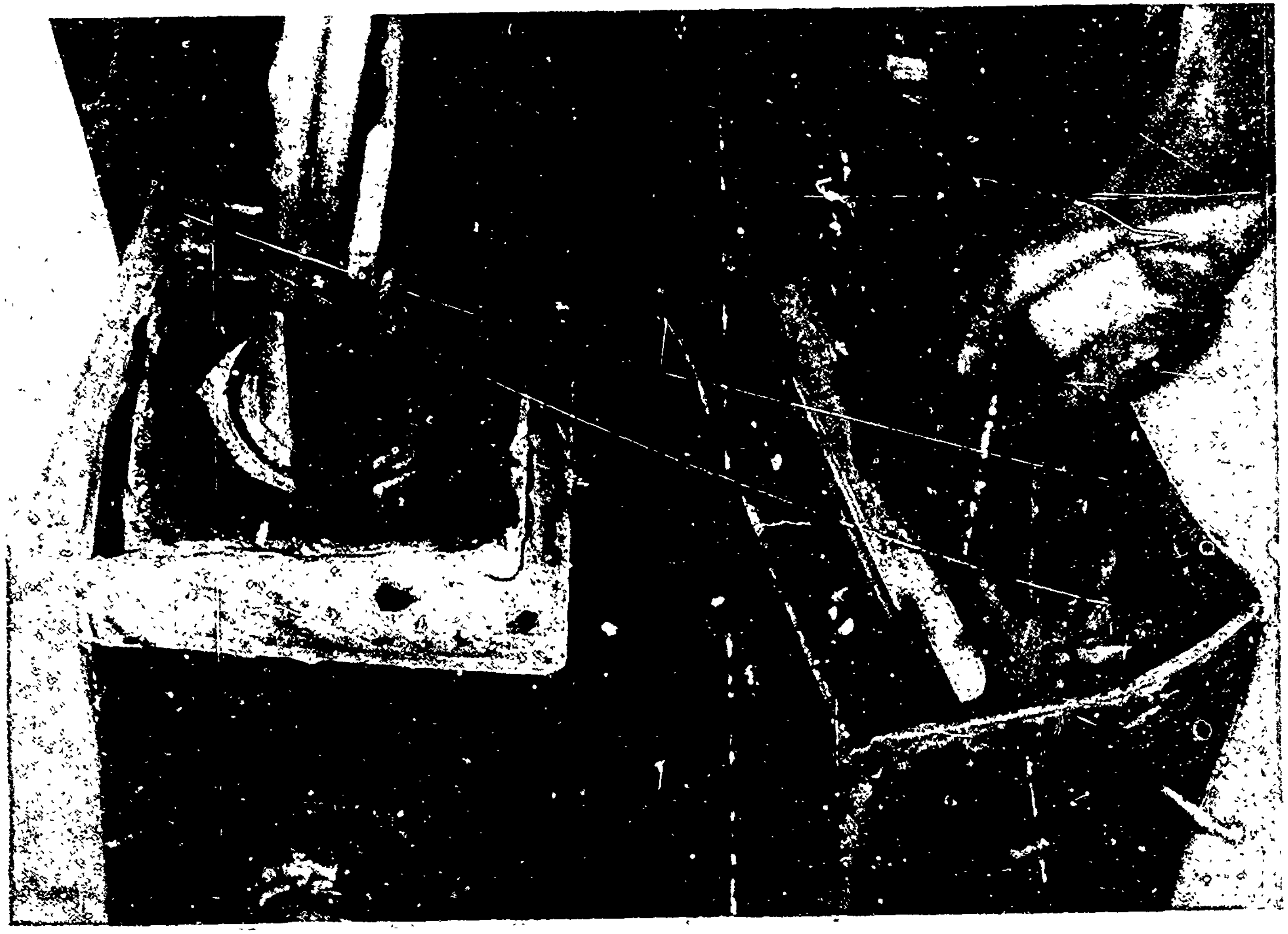


Figure 112. Experimental USAAVLABS/AAE Load-Limiter Assembly After Vietnam Use.

Figure 113. Experimental USAAVLABS/AAE Load-Linker Assembly After Vietnam Use.

I. Adaptability

A system of this nature is the most highly retrofittable since it is added to the aircraft equipment inventory without aircraft modification (except for stowage). Producibility of the units would be good and also economical. Mission flexibility would be good inasmuch as they may be stripped from the aircraft when not required.

SYSTEM 3

System 3 (Figure 98) consists of the basic elements of System 2 with the incorporation of quick-release ratchet buckle assemblies and the addition of throwover nets incorporating quick-tiedown and -release fasteners. These nets would be used for palletized or loose cargo and the AAE load attenuating strap assemblies.

Systems 3 through 6 will not be included in the evaluation referred to above. Components (such as net assemblies in System 2) will be evaluated in the group where they are incorporated.

SYSTEM 4

System 4 (Figure 99) consists of the basic strap and floor matrix without load attenuation, plus the use of load-limiting barriers with provisions for quick tiedown and release, and stowage.

A system of this nature can be considered more specialized for crew protection and the movement of much cargo on a routine basis (with no passengers or troops except for the flight crew). This is primarily due to the compartmentalization which results in reduced access (and safety) when egress is impeded. In this configuration, it also may be considered most useful in the fore and aft restraint direction, with less load attenuating capability in the lateral sense (or under conditions of secondary impact, rollover, etc.).

The typical barrier net stowage, shown at various locations (fixed or movable), provides considerable flexibility in attachment or in placement for so large a device. However, when stowed, such a unit would reduce the present clearance (dimension between side frames) and would reduce the present 6-1/2-foot x 7-1/2-foot cabin envelope. It would also be subject to considerable damage from close-fitting vehicles, whether placed on the side or overhead.

While these barriers do not now exist, they are in the initial stages of procurement by the Air Force.

SYSTEM 5

System 5, shown in Figure 100, is another special installation which depends on inflatables as load attenuators, while basic restraint of cargo against flight loads is by means of barriers and/or nets for loose cargo.

This compartmentalized version of a cargo restraint system has advantages where tiedowns are limited or eliminated, and where cargo is merely placed between portable bulkheads which consist of the barriers and inflated dunnage bags surrounding the cargo to hold it in position.

The use of equipment like this has little flexibility for an air vehicle which must maintain high flexibility for a variety of operating circumstances. It should also be noted that the dunnage bags provide a tremendously large target, and as such are highly susceptible to catching small-arms fire. This reduces their usefulness and makes pressure control (in the event of a crash) impossible to predict.

SYSTEM 6

System 6 (Figure 101) is another special case to provide for handling of large volumes of U.S. Army 40- x 48-inch wooden pallets. This system is basically advantageous for prepalletized cargo in which a portable pallet adapter would permit quick security of the pallet in the aircraft after being netted (to the pallet) in a prepared area. A crash restraint would be provided by compartmentalization using barriers. A system of this nature may be more useful in supply missions, where strict routine may be followed in delivery to a division base and where the logistical supply of the pallet adapter would be no problem. Of course, the features of this system would not be helpful when the cargo was prepalletized.

SYSTEM 7 (CATEGORY II)

The System 7 concept (Figure 102) provides load-limiting devices as a discrete package installed below the floor and connected to the existing tiedown rings. These energy absorbers would be supplemented by a low-elastic tiedown strap assembly of corresponding capacity incorporating quick-release and ratchet takeup features. These straps would be used for tiedown of both Class A and B cargo. Use of a high-capacity, low-elastic webbing material is necessary to insure a minimum strap deflection during stroking of the load limiter device. The system would also incorporate a multiple attachment quick-release bridle. (See the footnote about the bridle in System 2.) The load limiters would be line replaceable units.

A. Survivability

Using an energy absorption device such as a ball-tube unit with the tiedown ring connected to a cable, 90-percent survivability could be achievable in all load directions.

B. Crashworthiness

Independent attachment of the energy absorption device to the floor minimizes damage and detachment during the crash and permits full availability of the device.

C. Redundancy

Redundancy in the system will be related to the number of tiedowns used. Peak overloads could cause yielding in cable, frame cap, and floor rail.

D. Safety

This is the simplest of systems, with only strap assemblies being used, or, coming in contact with the man and the environment. Egress should be better than that provided by the existing (baseline) system in terms of the reduced number of straps used to retain the loads. Center-of-gravity shift with this system should not be common, although it may be a problem in restraining normal articles on palletized loads, unless some prepalletizing is provided. Units of this type (under the floor) should give ample failure warning by protruding if the unit has been stroked inadvertently.

E. Minimum Tiedowns

The number of tiedowns required will depend on the capacity of the load limiter.

F. Rapid Rigging

All cargo may be tied down rapidly, with the exception of the bulk cargo which must be wrapped with tiedown straps to be properly secured (or secured with nets designed for the system).

G. Sturdiness

System 7 would be low in weight and would require minimum maintenance. The energy absorption units are protected from environment, personnel mishandling, cargo movement, and all other environmental factors (except for exposure to variation in moisture and local aircraft

vibration). Straps and other release devices are in the cabin and are readily subject to inspection and replacement, as necessary.

H. Integral Installation

While energy absorption is accomplished with a special unit serving only that function, it is incorporated in the airframe as a structural component and is a line-replaceable unit if damaged.

I. Adaptability

As integral items, load limiters may be used on a retrofittable or new design basis; however, they add to the empty weight of the aircraft when built in.

SYSTEM 8

System 8 is an integral, self-stowing tiedown and release strap concept as shown in Figure 103. The existing tiedown fittings are replaced with an assembly which includes an energy absorber, a locking reel, and an automatic tensioning feature with self-stowing capability of the tiedown strap.

A. Survivability

More tiedowns may be necessary with this system to achieve 90-percent survivability, if incorporation of the take-up reel tensioning device requires a reduction in the load limiter stroke due to space limitations. Full pulse capability is assumed, however.

B. Crashworthiness

If they are fastened to the floor frames, load limiter units may either break loose or become reoriented in a crash involving damage to the floor frames. This may fail to develop full load, or may jam the straps.

C. Redundancy

Some loss of tiedown in the crushed area is expected, although adequate redundancy should be retained. Peak overloads could result in yielding of cable, frame cap, floor, and frame web.

D. Safety

Loose cargo may result if the inertia reel malfunctions. Unlocking of the reel may result from impact or rebound. If cargo were to move slowly, under flight load or change

in aircraft attitude, loss of tensioning may result as the cable slowly unreels. This unit would not be fail-safe unless a positive lock were incorporated. No egress problems are anticipated. Warning of unit stroking may be somewhat masked as a result of the tape take-up reel capability.

E. Minimum Tiedown

If design stroke is shortened as a result of available clearance, more than the minimum number of tiedowns will be needed for 90-percent g level in all directions.

F. Rapid Rigging

Good hookup and release performance is expected since sizing of straps and tensioning of straps is eliminated by the automatic features.

G. Sturdiness

System weight would be a function of the number of tiedowns which incorporate the individual units, reels, and self-reeling strap, as compared to a system in which one strap may be used at several alternate locations. Normal usage may result in seal damage and strap wear damage where it enters the seal, due to dirt and other foreign items. The take-up reel and locking mechanism may also require maintenance. If any hang-up occurs in the individual unit, additional hookup time would be required since another nearby assembly and strap must be selected for the cargo. Restraint strap reliability could be degraded from wear, as a result of reeling the unit in and out.

H. Integral Installation

This system would provide a good integral installation, with stowage provided for straps, and would provide maximum availability except for maintenance of functioning parts. (This assembly is not a completely passive device; repair of worn items would require floor removal.)

I. Adaptability

A retrofit installation would require rework in the areas of the floor, pan, and fitting, in addition to the floor frame. In the new design, the beam tiedown may be eliminated by an alternate installation scheme.

SYSTEM 9

System 9 consists of the energy-absorption units of System 7, supplemented with self-stowing sidewall nets and multilocation crash barriers (see Figure 104). The self-stowing cargo nets would include quick-release capability and reel-up features. Barriers would be used when using cargo nets or straps; tiedown is limited to securing the cargo for flight loads only. This also provides a means of compartmentalizing passenger and cargo areas.

A. Survivability

The basic survivability provided by this system would be by incorporation of load limiters, rather than by the inclusion of nets or barriers. An exception would be the use of a net for loose cargo (either palletized or unpalletized). Use of nets to provide restraint, through the incorporation of load limiters into a net assembly, could be very complex and would require considerable development. In use of barriers, the load limiters should be oriented in the direction of loads or should be cable actuated. This means the use of low extensible material to shorten the stroke of the barrier, which is characteristically a long stroke unit. Ninetieth percentile survivability would be feasible for fore and aft directions. However, a lateral condition would require a separate barrier since units installed for fore and aft loads would be of little value for highly skewed or side loads.

Tiedown of cargo for flight loads results in load breakaway, higher peak decelerations, and the need to absorb the kinetic energy of the free cargo. Restraint in all directions could not be achieved unless a piece of cargo were surrounded by barriers and structure. This system is best for forward and aft directions.

B. Crashworthiness

Localized loads may develop either from loads skewed into a barrier or fracture of a flight load tiedown. Secondary impact damage could result within the cabin, thereby reducing ultimate survivability. This seems much less desirable than continually restraining cargo and carrying the load down to rest from the initial impact.

C. Redundancy

Side crashes may change orientation of attachment and result in increased barrier stroke. If minimum or flight load restraints are used, no redundancy would be considered

available unless provided by inherent plasticity of the attaching structure.

D. Safety

The use of barriers blocks direct passage and thereby impedes egress. If special passageways are provided, they may be damaged or obstructed in a crash. If left open they may impair the load retention capability of the system.

If a system requires two functional steps in securing loads (tiedown flight loads and barrier installation for crash loads), then laxity in the use of the entire system may be encouraged either through misunderstanding or development of poor practice. Loads impacting the structure may be expected in all but a directly forward crash. This may result in secondary failure. Barrier wear, or wear of nets which are unprotected, may create safety problems.

E. Minimum Tiedown

The advantage of a net-barrier combination system is one of minimizing tiedown before aircraft lift-off. However, if loads are not completely secured, aircraft movement may make it difficult to install barriers and secure them properly, thereby causing unsafe conditions. Barrier design must be geared to maximum weight of cargo; therefore, security of the net must also be the same regardless of the cargo being isolated. The establishment of different security methods for different loads would be confusing.

F. Rapid Rigging

The advantages of the barrier are that it may be designed to be quickly emplaced, and that one setup arrangement can be used for all purposes. The primary advantage of the curtain type barrier is not so much its time saving in installation but in its rapid removal to debark the cargo.

G. Sturdiness

Use of barriers and nets as flyaway equipment would add considerable weight if provisions are made for the variety of cargo which is usually encountered. Four Dacron nets in a system would weigh in excess of 200 pounds. Barriers would be approximately the same weight but would require additional attaching hardware, receptacles, supports, or special frames. Where special stowage could not be provided, barriers which intrude into the normal cabin

envelope would suffer considerable damage from abrasion and movement of cargo. Replacement of these installations would be costly.

H. Integral Installation

This installation may be considered a semiautomatic or integral installation.

I. Adaptability

This type of system (which would minimize cargo tiedown to technical manual type restraint) could supply barriers for a pure cargo version aircraft as either retrofit or new design installations. From the standpoint of the versatility of cabin space, the use of barriers, net installation, and required stowage would degrade the cabin envelope.

ALTERNATE SYSTEM 9A

This system, as illustrated in Figure 105, would use annealed stainless steel cable in the floor rails (between tiedown fittings) as energy absorbing units.

A. Survivability

This type load limiter could be used for specific fore or aft loads. It has almost unidirectional capability, since lateral or aft loads for the same tiedown unit would put the bulk of the load into the fitting ferrule surrounding the cable. Individual cables, rather than ganged cables, would simplify load determination and design of load level.

SYSTEM 10 (CATEGORY III)

System 10 (Figure 106) utilizes existing tiedown fittings secured to the existing floor frames through four straddling tension rods. Beneath each tiedown fitting, the floor frames incorporate energy absorbing inserts of honeycomb material which would be crushed as the tiedown fitting is pulled from the floor. (The existing honeycomb cells must be reoriented to perform as an energy absorber and the frame stiffness characteristics restored through the use of doublers.)

A. Survivability

This load-limiting frame rework could be designed for high survivability except that the attachment for the honeycomb unit would function primarily as designed under an up load. Load limited control and breakout force would

be highly unpredictable for shallow tiedown angles. This would limit its usefulness as a multidirectional unit. Hang-up in pull of the rod will create peak loads which could rupture restraint.

B. Crashworthiness

In a downward or forward crash with distortion, collapsing or tearing of the frames in which the honeycomb unit is located would completely change the load limiting characteristics of the section. Frames not directly involved in the ground impact would probably maintain their integrity; cargo would probably be retained in a forward-angled crash but might suffer in the rebound condition in a high-speed forward crash at shallow angles.

C. Redundancy

The load will probably be retained in a crash where a large number of tiedowns are used.

D. Safety

All safety requiremen would be met by this system, with the possible exception .. the ability to retain loads at constant level from all directions and the fail-safety of the limiter actuating rods.

E. Minimum Tiedown

The characteristics of this system would be similar to System 7, with the exception that specific additional tiedowns would be required for various directions due to the limitations of near-vertical loading requirements.

F. Rapid Rigging

This system would require that a number of attachments be made individually commensurate with the design load level. Tiedowns would be based on crash load criteria. Straps would be used for all types of cargo.

G. Sturdiness

This system is intended for under-the-floor installation; consequently, it would be removed from all normal handling abuses. Environmental degradation may affect the material involved; however, these conditions would be no worse than those found in the normal use of the aircraft, and could be controlled under a normal inspection period for the structure. Inadvertent overloading may result in premature removal. The incorporation of such a unit in a

narrow, lightweight frame may result in high weight, in addition to the weight of the crushing bar and the multipoint symmetrical straddling attachments required.

H. Integral Installation

System 10 would be an integral installation since the load limiting units would be incorporated in the airframe. However, replacement of these units would not be simple since bonding to the beam requires special tools. Means of attachment which may impair the normal functions of the frame must be avoided.

I. System Adaptability

As here conceived, this system is more adaptable to existing frames than to new installations. Use of such a system would require considerable development tests; load limiting capability must be demonstrated. The inclusion of the unit would not impair the basic function of the floor frame. A detailed stress analysis of each location would be required to determine that normal loads which the frame carries follow the same load paths, and that the frame has not been made fatigue critical, or that other structural problems have not been created. The modified frame must include a tolerance for unit overloading without impairment of the basic frame function.

Research and development costs connected with these design problems are expected to be high.

SYSTEM 11

This design concept utilizes the airframe structure in deformation during a crash by attaching additional structural members to the relatively softer parts of the fuselage between the frames. The restraint loads are primarily transmitted through barrier nets to the fuselage frames. This system would be used with nets and barriers as shown in Figure 107.

A. Survivability

This system would be particularly suited to cargo installations in which crew and/or passengers were primarily confined to fore and aft locations. The primary structure used to attenuate the crash loads would perform the required work in the forward section, but the cargo would require additional restraint or other means of absorbing crash energy in lateral and rebound conditions.

B. Crashworthiness

The crashworthiness of such a system would be satisfactory in the forward and aft directions, except as may be influenced by change in stroke (depending on the direction of the crash).

C. Redundancy

Retention of the load under any crash conditions would be determined by the direction of the crash and the supplemental restraints surrounding the load under the influence of the crash, as well as the effects of secondary failures.

D. Safety

To be most useful, the barriers in this system must completely surround the load and be capable of absorbing the kinetic energy involved and avoiding secondary failures due to the movement of the cargo into the structure. Egress would no doubt be impaired, unless special provisions for passageways are made. Personnel safety might also be endangered by protrusion of cargo or vehicles locally through the nets or barriers. There may also be a tendency for barrier release by personnel before touchdown to eliminate the confined feeling created by the system. This laxity may also occur to obtain flexibility and/or unload the cargo quickly.

E. Minimum Tiedown

This system would be advantageous in reduction of lash-up of the cargo by means of a variety of sliding curtains and compartmentalization. But, on unloading, some difficulty and/or snagging may be experienced in removing the barriers because of movement of the cargo during flight or landing.

F. Rapid Rigging

This system may be considered a semiautomatic type, since it would utilize barriers for fore and aft restraint; these barriers may be stowed at the sidewalls or overhead and may then be moved in position ahead or behind the cargo depending on the location and size. These barriers would be used to partition off vehicles. Self-stowing nets would be required for loose cargo and pallets. This quick partitioning for fore-and-aft restraints of the loads would be the primary advantage of the system.

G. Sturdiness

This system would require additional weight in the soft parts of the structure to retain loads under crash conditions and to provide for load distribution by local yielding of the skin and stringers in the area of attachment. This is primarily a bidirectional system. Also, if cargo is improperly released at the time of unloading, aircraft damage may ensue. Under these conditions the airframe repair may be extensive, thereby reducing its availability.

H. Integral Installation

Another advantage of this system is that it provides an idealized integral installation for cargo carrying aircraft in that it utilizes the existing airframe structure for dispersion of crash energy without the need for providing specific load limiting components. Load limiting airframe components would not be line-replaceable units. However, a corresponding disadvantage is that the nets and barriers are subject to considerable wear and tear from cargo movement. Stowage provisions may utilize valuable portions of the cabin volume for a large quantity of units.

I. Adaptability

As an integral system, System 11 is typical of those that may not lend themselves to retrofittable use. System 11 may be considered for new aircraft designs of more specialized purpose. It will no doubt require extensive new structural analysis in which dynamic criteria for crash loads are considered along with flight load criteria. Cabin structural weight and volume trade-offs would be required. Unique stowage systems would be needed and structural demonstration tests would be required.

SYSTEM 12

System 12 (Figure 108) utilizes a dual-sided frame construction with an entrained member (stroking unit) sandwiched between the frame. The frame sideplates would yield under loads through appropriate attaching points as the center bulb-like section is pulled inward. These frames would be an integral portion of the cabin structure and would serve the normal function of carrying all airframe loads in addition to the cargo restraint loads.

As a true integral installation, this system would have all the advantages and disadvantages of System 11 and would differ only in energy absorption, sturdiness, location of the barrier attachments, and system adaptability.

SYSTEM 13

System 13, as shown in Figure 109, utilizes a subfloor structure containing longitudinal extruded T-sections for stiffening. Energy absorption is achieved when loading of the floor tiedown fitting fails at a fused bolt section and causes an upward floor displacement. This displacement or bowing results in bending of T-sections and their captive channels.

A. Survivability

Design survivability of a unique floor system such as System 13 may be achieved only if the dynamic loads on the tiedown fitting are essentially vertical. Even in this direction of load, a peak may be experienced as a result of a need for a fusing link between the tiedown fitting and the load attenuating sections. Crash loads in restraints set at shallow angles in forward, aft, or lateral directions would cause failure of the fitting without actuation of the load limiters, due to the exceedingly high stiffness of the floor in these directions. This would be the case with the normal relationship between the cargo floor and the fuselage frames and supporting structure. A floor load attenuating system of this type may be used if another means were developed to carry the normal flight loads into the structure, and if the floor could be made to move relative to the aircraft structure by yielding relatively soft structure in fore, aft, and lateral directions.

B. Crashworthiness

Use of present floor design provides high crashworthiness. If floor attachments were softened, buckling and reduction of cabin envelope might occur.

C. Redundancy

Redundancy would be determined by floor design.

D. Safety

Any floor load attenuating system would have excellent safety characteristics as long as it did not interfere with normal flight structural loading. Floor buckling would interfere with personnel movement and would reduce occupied volume. Personnel injuries may result if the floor tears or fragments in any way.

E. Minimum Tiedown

A floor load attenuating system could achieve minimum tiedown provided the weight penalty for high capacity

floor fittings could be tolerated. However, more than the minimum tiedowns would be required for the system shown due to its limited directional use for effective cargo restraint.

F. Rapid Rigging

Load lash-up and release would be less than minimum with this system inasmuch as the unidirectional load handling capability of the fittings would require pulleys at each fitting to get the load into the floor in the proper direction. This would not encourage high crew acceptance or utilization in a hostile environment. Use of this equipment may vary with Class A and B loads because of the tiedown angles required.

G. Sturdiness

The requirements for pulleys and other additional hardware above the floor surface would subject the system components to considerable damage and environmental degradation in addition to added weight. Maintenance of the system would be high.

H. Integral Installation

While this system could be considered wholly integral within the helicopter airframe, it would be difficult to achieve as a replacement unit.

I. System Adaptability

The system described would be more uniquely fitted to retrofit application than to new designs.

SYSTEM 14

System 14 (Figure 110) consists of a series of inflatable modular bags integrated into the overhead structure of the aircraft. An automatic push-button inflation system would be utilized to inflate bags in various positions, either forward or aft of the cargo (and on either or both sides of the cargo), after positioning the cargo in place. The bag endings would require attachment to floor or side structure.

For removal, cargo attachments would be released and the bags deflated and stowed by a vacuum process. Under crash conditions these bags would serve to attenuate the crash loads and contain the cargo which otherwise would not be restrained. Pressure regulating control valves would be required to limit bag pressure and furnish a bleed control system during load deceleration.

A. Survivability

This system could conceivably control the movement of loads in all directions under all crash conditions, provided that extensive development was first carried out for the bag deployment, attachment, and pressure regulation, as well as for the bleed control systems and the required control for the removal of the restraint.

B. Crashworthiness

Highly localized loads, load direction, and condition of the system may greatly influence crashworthiness.

C. Redundancy

Failure of inflatables for any reason will affect this factor.

D. Safety

This system would impose a severe penalty on the cabin from the standpoint of distinct compartmentalization and reduction of cabin flexibility. Egress would be limited to the local area surrounding crew or passengers. It is possible that this confinement would discourage use of the system. This system does not appear to be psychologically suited for use with passengers.

E. Minimum Tiedown

While a minimum restraint would be used for each individual piece of cargo, serious questions arise in loading sequence, load positioning, and cabin obstruction before the entire cabin load is accomplished.

F. Rapid Rigging

In general, very rapid rigging could be accomplished with this system (in an ideal sense) if loads could be moved in and immediately secured.

G. Sturdiness

A decided deficiency of the system would be its susceptibility to hostile environment, no doubt suffering damage from even small-arms fire. The nature of the system would make it highly susceptible because of the large target area involved and the possibility of rupturing or tearing of the bags. This susceptibility to hostile environment, along with ordinary cargo handling conditions, may inactivate the system at any time.

H. Integral Installation

The system could be considered integral, and replaceable units could be used.

I. System Adaptability

This system could be adapted for new or retrofit installations, provided a loss of cargo cabin envelope were not critical.

6.3 CARGO RESTRAINT SYSTEM SELECTION

The selection of a cargo restraint system was determined from a qualitative evaluation of each candidate system. The results of the evaluation are presented in Table XII in terms of a numerical weighted process. This was accomplished by:

1. Establishing an index of merit (with a maximum value of 10) to amplify the relative degree of importance of each of the qualitative factors (see Section 6.1). The rating is as follows:

Qualitative Factor	Index of Merit
Survivability	10
Crashworthiness	8
Redundancy	8
Safety	5
Minimum tiedowns	5
Rapid rigging	5
Sturdiness	2
Integral installation	1
Adaptability	1

2. Assigning a weighted value (with maximum of 10) to each system objective which is based on the capability of each system to comply with the qualitative factors (as analyzed in Section 6.2). An example is given below.

3. Multiplying the weighted value by the index of merit for each system per objective to obtain a numerical value (called the weighted index). The highest value represents the highest rating.

4. Summing the weighted index values for each system to determine the most adaptable system.

The data in Table XII offers a comparison of system compliance to the qualitative factors peculiar to each. The numbers in boxes reflect the highest ratings assigned. A "perfect"

TABLE XII. QUALITATIVE EVALUATION OF RESTRAINT SYSTEMS

Qualitative Factors	Index of Merit	Weighted Index of Restraint Systems													
		Category I*						Category II			Category III				
		1*	2	3**	4*	5**	6**	7	8	9	10	11	12	13	14
A. Survivability	10	-	$\boxed{100}$	-	-	-	-	$\boxed{100}$	$\boxed{100}$	50	30	50	50	20	$\boxed{100}$
B. Crashworthiness	8	-	$\boxed{80}$	-	-	-	-	$\boxed{80}$	64	40	48	40	40	32	16
C. Redundancy	8	-	0	-	-	-	-	56	$\boxed{64}$	40	48	40	40	$\boxed{64}$	16
D. Safety	5	-	30	-	-	-	-	$\boxed{40}$	10	10	30	10	10	25	0
E. Minimum Tiedown	5	-	40	-	-	-	-	$\boxed{50}$	30	50	25	40	40	15	40
F. Rapid Rigging	5	-	40	-	-	-	-	25	$\boxed{50}$	25	25	25	25	20	$\boxed{50}$
G. Sturdiness	2	-	4	-	-	-	-	$\boxed{20}$	10	6	16	6	10	8	0
H. Integral Installation	1	-	4	-	-	-	-	4	6	6	3	8	$\boxed{10}$	7	$\boxed{10}$
I. Adaptability	1	-	$\boxed{10}$	-	-	-	-	8	4	8	5	1	5	1	8
Total	45	-	308	-	-	-	-	$\boxed{383}$	338	235	230	220	230	192	240

* System 1 is incapable of meeting survivability goal.

** The Category I Systems 3, 4, 5, and 6 for which no weighted values are shown were previously eliminated from the comparison because of their exposed nature.

system would have completely satisfied all the objectives and accrued a total of 450 points.

A detailed example of the method used to assign weighted values is presented in Table XIII for the survivability objective. The highest value (maximum of 10) is assigned to a system which is capable of restraining cargo effectively in all directions. This is inclusive of restraint pertinent to the 90th percentile in the helicopter's longitudinal and lateral directions, with the forward direction considered most important.

TABLE XIII. EXAMPLE OF WEIGHTED VALUES FOR THE SURVIVABILITY OBJECTIVE

System No.	Criteria Assessment	Weighted Value Assigned	Index of Merit	Weighted Index
1	Affords no survivability to crash impulse.	0	10	0
2	Full capability possible with sufficient tiedowns.	10	10	100
3-6	(Excluded. See System 3 discussion.)			
7	Full capability possible with sufficient tiedowns.	10	10	100
8	Full capability possible with sufficient tiedowns.	10	10	100
9	Exploiting use of uni-directional barriers for crash loads, with additional restraint only for flight loads, degrades system from a survivability standpoint to one direction only. Full survivability would be achieved if cargo were surrounded by barriers.	5	10	50
10	Load limiters primarily capable of upload. High breakout forces expected at most (especially low) hookup angles, seriously degrading system.	3	10	30

B. Crashworthiness

The crashworthiness of such a system would be satisfactory in the forward and aft directions, except as may be influenced by change in stroke (depending on the direction of the crash).

C. Redundancy

Retention of the load under any crash conditions would be determined by the direction of the crash and the supplemental restraints surrounding the load under the influence of the crash, as well as the effects of secondary failures.

D. Safety

To be most useful, the barriers in this system must completely surround the load and be capable of absorbing the kinetic energy involved and avoiding secondary failures due to the movement of the cargo into the structure. Egress would no doubt be impaired, unless special provisions for passageways are made. Personnel safety might also be endangered by protrusion of cargo or vehicles locally through the nets or barriers. There may also be a tendency for barrier release by personnel before touchdown to eliminate the confined feeling created by the system. This laxity may also occur to obtain flexibility and/or unload the cargo quickly.

E. Minimum Tiedown

This system would be advantageous in reduction of lash-up of the cargo by means of a variety of sliding curtains and compartmentalization. But, on unloading, some difficulty and/or snagging may be experienced in removing the barriers because of movement of the cargo during flight or landing.

F. Rapid Rigging

This system may be considered a semiautomatic type, since it would utilize barriers for fore and aft restraint; these barriers may be stowed at the sidewalls or overhead and may then be moved in position ahead or behind the cargo depending on the location and size. These barriers would be used to partition off vehicles. Self-stowing nets would be required for loose cargo and pallets. This quick partitioning for fore-and-aft restraints of the loads would be the primary advantage of the system.

G. Sturdiness

This system would require additional weight in the soft parts of the structure to retain loads under crash conditions and to provide for load distribution by local yielding of the skin and stringers in the area of attachment. This is primarily a bidirectional system. Also, if cargo is improperly released at the time of unloading, aircraft damage may ensue. Under these conditions the airframe repair may be extensive, thereby reducing its availability.

H. Integral Installation

Another advantage of this system is that it provides an idealized integral installation for cargo carrying aircraft in that it utilizes the existing airframe structure for dispersion of crash energy without the need for providing specific load limiting components. Load limiting airframe components would not be line-replaceable units. However, a corresponding disadvantage is that the nets and barriers are subject to considerable wear and tear from cargo movement. Stowage provisions may utilize valuable portions of the cabin volume for a large quantity of units.

I. Adaptability

As an integral system, System 11 is typical of those that may not lend themselves to retrofittable use. System 11 may be considered for new aircraft designs of more specialized purpose. It will no doubt require extensive new structural analysis in which dynamic criteria for crash loads are considered along with flight load criteria. Cabin structural weight and volume trade-offs would be required. Unique stowage systems would be needed and structural demonstration tests would be required.

SYSTEM 12

System 12 (Figure 108) utilizes a dual-sided frame construction with an entrained member (stroking unit) sandwiched between the frame. The frame sideplates would yield under loads through appropriate attaching points as the center bulb-like section is pulled inward. These frames would be an integral portion of the cabin structure and would serve the normal function of carrying all airframe loads in addition to the cargo restraint loads.

As a true integral installation, this system would have all the advantages and disadvantages of System 11 and would differ only in energy absorption, sturdiness, location of the barrier attachments, and system adaptability.

SYSTEM 13

System 13, as shown in Figure 109, utilizes a subfloor structure containing longitudinal extruded T-sections for stiffening. Energy absorption is achieved when loading of the floor tiedown fitting fails at a fused bolt section and causes an upward floor displacement. This displacement or bowing results in bending of T-sections and their captive channels.

A. Survivability

Design survivability of a unique floor system such as System 13 may be achieved only if the dynamic loads on the tiedown fitting are essentially vertical. Even in this direction of load, a peak may be experienced as a result of a need for a fusing link between the tiedown fitting and the load attenuating sections. Crash loads in restraints set at shallow angles in forward, aft, or lateral directions would cause failure of the fitting without actuation of the load limiters, due to the exceedingly high stiffness of the floor in these directions. This would be the case with the normal relationship between the cargo floor and the fuselage frames and supporting structure. A floor load attenuating system of this type may be used if another means were developed to carry the normal flight loads into the structure, and if the floor could be made to move relative to the aircraft structure by yielding relatively soft structure in fore, aft, and lateral directions.

B. Crashworthiness

Use of present floor design provides high crashworthiness. If floor attachments were softened, buckling and reduction of cabin envelope might occur.

C. Redundancy

Redundancy would be determined by floor design.

D. Safety

Any floor load attenuating system would have excellent safety characteristics as long as it did not interfere with normal flight structural loading. Floor buckling would interfere with personnel movement and would reduce occupied volume. Personnel injuries may result if the floor tears or fragments in any way.

E. Minimum Tiedown

A floor load attenuating system could achieve minimum tiedown provided the weight penalty for high capacity

floor fittings could be tolerated. However, more than the minimum tiedowns would be required for the system shown due to its limited directional use for effective cargo restraint.

F. Rapid Rigging

Load lash-up and release would be less than minimum with this system inasmuch as the unidirectional load handling capability of the fittings would require pulleys at each fitting to get the load into the floor in the proper direction. This would not encourage high crew acceptance or utilization in a hostile environment. Use of this equipment may vary with Class A and B loads because of the tiedown angles required.

G. Sturdiness

The requirements for pulleys and other additional hardware above the floor surface would subject the system components to considerable damage and environmental degradation in addition to added weight. Maintenance of the system would be high.

H. Integral Installation

While this system could be considered wholly integral within the helicopter airframe, it would be difficult to achieve as a replacement unit.

I. System Adaptability

The system described would be more uniquely fitted to retrofit application than to new designs.

SYSTEM 14

System 14 (Figure 110) consists of a series of inflatable modular bags integrated into the overhead structure of the aircraft. An automatic push-button inflation system would be utilized to inflate bags in various positions, either forward or aft of the cargo (and on either or both sides of the cargo), after positioning the cargo in place. The bag endings would require attachment to floor or side structure.

For removal, cargo attachments would be released and the bags deflated and stowed by a vacuum process. Under crash conditions these bags would serve to attenuate the crash loads and contain the cargo which otherwise would not be restrained. Pressure regulating control valves would be required to limit bag pressure and furnish a bleed control system during load deceleration.

A. Survivability

This system could conceivably control the movement of loads in all directions under all crash conditions, provided that extensive development was first carried out for the bag deployment, attachment, and pressure regulation, as well as for the bleed control systems and the required control for the removal of the restraint.

B. Crashworthiness

Highly localized loads, load direction, and condition of the system may greatly influence crashworthiness.

C. Redundancy

Failure of inflatables for any reason will affect this factor.

D. Safety

This system would impose a severe penalty on the cabin from the standpoint of distinct compartmentalization and reduction of cabin flexibility. Egress would be limited to the local area surrounding crew or passengers. It is possible that this confinement would discourage use of the system. This system does not appear to be psychologically suited for use with passengers.

E. Minimum Tiedown

While a minimum restraint would be used for each individual piece of cargo, serious questions arise in loading sequence, load positioning, and cabin obstruction before the entire cabin load is accomplished.

F. Rapid Rigging

In general, very rapid rigging could be accomplished with this system (in an ideal sense) if loads could be moved in and immediately secured.

G. Sturdiness

A decided deficiency of the system would be its susceptibility to hostile environment, no doubt suffering damage from even small-arms fire. The nature of the system would make it highly susceptible because of the large target area involved and the possibility of rupturing or tearing of the bags. This susceptibility to hostile environment, along with ordinary cargo handling conditions, may inactivate the system at any time.

H. Integral Installation

The system could be considered integral, and replaceable units could be used.

I. System Adaptability

This system could be adapted for new or retrofit installations, provided a loss of cargo cabin envelope were not critical.

6.3 CARGO RESTRAINT SYSTEM SELECTION

The selection of a cargo restraint system was determined from a qualitative evaluation of each candidate system. The results of the evaluation are presented in Table XII in terms of a numerical weighted process. This was accomplished by:

1. Establishing an index of merit (with a maximum value of 10) to amplify the relative degree of importance of each of the qualitative factors (see Section 6.1). The rating is as follows:

Qualitative Factor	Index of Merit
Survivability	10
Crashworthiness	8
Redundancy	8
Safety	5
Minimum tiedowns	5
Rapid rigging	5
Sturdiness	2
Integral installation	1
Adaptability	1

2. Assigning a weighted value (with maximum of 10) to each system objective which is based on the capability of each system to comply with the qualitative factors (as analyzed in Section 6.2). An example is given below.

3. Multiplying the weighted value by the index of merit for each system per objective to obtain a numerical value (called the weighted index). The highest value represents the highest rating.

4. Summing the weighted index values for each system to determine the most adaptable system.

The data in Table XII offers a comparison of system compliance to the qualitative factors peculiar to each. The numbers in boxes reflect the highest ratings assigned. A "perfect"

TABLE XII. QUALITATIVE EVALUATION OF RESTRAINT SYSTEMS

Qualitative Factors	Index of Merit	Weighted Index of Restraint Systems													
		Category I*						Category II			Category III				
		1*	2	3**	4*	5**	6**	7	8	9	10	11	12	13	14
A. Survivability	10	-	$\boxed{100}$	-	-	-	-	$\boxed{100}$	$\boxed{100}$	50	30	50	50	20	$\boxed{100}$
B. Crashworthiness	8	-	$\boxed{80}$	-	-	-	-	$\boxed{80}$	64	40	48	40	40	32	16
C. Redundancy	8	-	0	-	-	-	-	56	$\boxed{64}$	40	48	40	40	$\boxed{64}$	16
D. Safety	5	-	30	-	-	-	-	$\boxed{40}$	10	10	30	10	10	25	0
E. Minimum Tiedown	5	-	40	-	-	-	-	$\boxed{50}$	30	50	25	40	40	15	40
F. Rapid Rigging	5	-	40	-	-	-	-	25	$\boxed{50}$	25	25	25	25	20	$\boxed{50}$
G. Sturdiness	2	-	4	-	-	-	-	$\boxed{20}$	10	6	16	6	10	8	0
H. Integral Installation	1	-	4	-	-	-	-	4	6	6	3	8	$\boxed{10}$	7	$\boxed{10}$
I. Adaptability	1	-	$\boxed{10}$	-	-	-	-	8	4	8	5	1	5	1	8
Total	45	-	308	-	-	-	-	$\boxed{383}$	338	235	230	220	230	192	240

* System 1 is incapable of meeting survivability goal.

** The Category I Systems 3, 4, 5, and 6 for which no weighted values are shown were previously eliminated from the comparison because of their exposed nature.

system would have completely satisfied all the objectives and accrued a total of 450 points.

A detailed example of the method used to assign weighted values is presented in Table XIII for the survivability objective. The highest value (maximum of 10) is assigned to a system which is capable of restraining cargo effectively in all directions. This is inclusive of restraint pertinent to the 90th percentile in the helicopter's longitudinal and lateral directions, with the forward direction considered most important.

TABLE XIII. EXAMPLE OF WEIGHTED VALUES FOR THE SURVIVABILITY OBJECTIVE

System No.	Criteria Assessment	Weighted Value Assigned	Index of Merit	Weighted Index
1	Affords no survivability to crash impulse.	0	10	0
2	Full capability possible with sufficient tiedowns.	10	10	100
3-6	(Excluded. See System 3 discussion.)			
7	Full capability possible with sufficient tiedowns.	10	10	100
8	Full capability possible with sufficient tiedowns.	10	10	100
9	Exploiting use of uni-directional barriers for crash loads, with additional restraint only for flight loads, degrades system from a survivability standpoint to one direction only. Full survivability would be achieved if cargo were surrounded by barriers.	5	10	50
10	Load limiters primarily capable of upload. High breakout forces expected at most (especially low) hookup angles, seriously degrading system.	3	10	30

TABLE XIII - Continued				
System No.	Criteria Assessment	Weighted Value Assigned	Index of Merit	Weighted Index
11	Primarily fore and aft survivability obtainable.	5	10	50
12	Essentially the same as System 11 for fore and aft restraint.	5	10	50
13	Essentially the same as System 10 with primarily vertical load limiter effectiveness. Fuse link required to limit peak loads.	2	10	20
14	Multidirectional restraint capability with cargo surrounded by air bags.	10	10	100

The remaining eight qualitative factors were assessed in the same manner; results are discussed below on a system basis.

This method of evaluation (assigning weighted index points) results in a relative comparison of the candidate restraint systems. The resultant values are heavily influenced by the operating environment and the feasibility of adapting each system for cargo restraint. The data in Table XII shows that the highest total index value belongs to System 7, followed by Systems 8 and 2, in that order.

In this ranking, System 7 shows a superiority in five of the nine design objectives, whereas the others excel in only three. As expected, all three systems show the maximum and equal dynamic pulse capability; however, Systems 7 and 2 are rated higher than System 8 in crashworthiness, and System 7 is rated higher than both other systems in safety, minimum tiedown, and sturdiness (environmental and maintenance factors). Systems 7 and 8 are quite similar, but System 7 lacks the obvious maintenance problems which would degrade availability.

The choice between these two systems for the mission effectiveness was therefore made in favor of System 7.

6.4 CANDIDATE ENERGY ABSORBER SELECTION

The selection of a candidate energy absorber for use as an integral part of the CH-47 helicopter restraint system was determined by a weighted evaluation process. In following paragraphs the energy absorber units are listed (with pertinent remarks) and evaluated prior to selection.

Candidate Energy Absorber Units

1. AAE Tube-Ball Unit

    a. Already designed for inline use with strap assemblies.

    b. Appears easily adaptable for attaching support structure within existing floor fitting locations.

    c. The capacity of the 5K unit (already developed) can be increased with relatively little additional development.

    d. Cable assembly component makes unit unidirectional when installed in a vertical position below the aircraft floor level.

    e. Meets load-deflection envelope requirements.

2. AAE Wire-Bending Device

    a. Involves the working of close tolerance parts; therefore, requires more development to reduce cost and improve tooling.

    b. Unit is compact.

    c. Can be installed under floor with modification.

    d. Meets load-deflection envelope requirements within reasonable load tolerance.

    e. Sufficiently developed for operational use as inline units.

3. Aeroquip Split Tube

    a. Must be prepulled to eliminate peak loads.

    b. Shear pin tolerance critical for initial peak load.

c. Expected weight value to be outside acceptable limits.

d. Must be located at the stroke length below the floor for final extension, unless tube is capable of pivoting.

4. VZA Metal Tube-Bending Device

a. Not as efficient as AAE wire-bending device.

b. In present configuration, unit is unidirectional when used for below-the-floor installation.

c. Anticipate same observation as Item 2a.

d. Cost, weight, and performance factors are not available.

e. Fittings must be designed for add-on application.

5. VZA Model LL-3

a. Requires redesign to bring load level to design values.

b. Same as Item 3d.

6. VZA LL-5

a. Unit is not compact.

b. Unit is lightweight (as shown).

c. No simple attachment to floor frames or floor pan.

d. Same as Item 3d.

7. VZA Compression Strut

a. Must increase load to design levels.

b. Beam attachments are not easily accomplished with existing hardware design.

c. Since it is a compression strut it is more difficult to tie to a D-ring.

d. Same as Item 3d.

8. <u>MRI Rolling Ring Energy Absorber</u>

   a. Attachments to supporting structure may present design problem. Attachments may be limited to upper and lower portions on outer tube.

   b. More development is required.

   c. Must be more specific on unit weight for 5K energy absorber. A 1/4-pound differential could result in a 20-percent variation.

   d. Same as Item 3d.

   e. Need data to determine percent of peak force to average force.

9. <u>Boeing Compression or Tension Peel Strut</u>

   a. Peeling of metal occurs outside of strut and may be undesirable as an inline energy absorber.

   b. Redesign of attachments may be necessary because of limited tie-in locations. Peeling material must be contained.

   c. Same as Item 3d.

   d. May be limited to integral installation below floor.

   e. Not multidirectional in present form for installation below aircraft floor level.

10. <u>Split-Tube Tiedown Energy Absorber</u>

   a. Development is required, since unit is in concept form.

   b. Peeling of metal occurs outside of unit configuration; therefore unit cannot be installed close to existing tiedown locations.

11. <u>Rail Splitter</u>

   a. Unit is unidirectional when used for integral installation.

   b. Development is required.

   c. Redesign of floor beam is necessary.

12. Frangible Tube Device

Unit is a compression member; therefore it has limited use as a cargo restraint device.

13. Crushable Cone

a. Expect weight-to-volume factor to be large.

b. Development is required.

c. Other concepts are more adaptable.

14. Accordion

a. Development is required.

b. Compactness within tiedown receptacle pan area could be difficult to achieve.

c. May require redesign of floor pan.

15. Canister Energy Absorber

a. Other concepts are more suitable.

b. It must maintain pressure level, which requires maintenance.

c. Weight-to-volume ratio is excessive.

16. ARDE Load Limiter

a. Unit is relatively heavy.

b. Further development is being undertaken by ARDE.

c. In its present form, unit is unidirectional when used for integral installation.

17. Honeycomb Core Energy Absorber

a. Similar to crushable cone.

b. Expect high weight-to-volume ratio to be unsatisfactory for cargo restraint.

18. Stainless Steel Strap

a. Development is required for tiedown net use.

b. Elongation properties are about 30 to 40 percent for 80 to 90 percent of breaking strength.

19. Peck & Hale Shock Expander

 a. In development stage.

 b. Net application appears to have merit.

 c. Development required.

 d. Combined weight of these units into a single net application could result in a relatively heavy item.

20. Liquid Spring

 Heavy unit.

21. Solid Medium

 Heavy unit.

22. Inflatables

 Constant load difficult to obtain.

Evaluation Items

The items chosen for evaluation of the energy absorber units are:

1. Weight

2. Development

 a. Device is new design.

 b. Continued efforts are required on existing devices.

3. Design Requirements

 a. Attachments (floor, frame, end fittings).

 b. Design requirement to make unit workable in the three impact directions.

4. Load Limiting Direction

 a. Unidirectional (under floor).

 b. Multidirectional (under floor).

5. Efficiency

   a. Initial peak-to-average pull load.

   b. Percentage of square pulse (load-deflection envelope).

6. System Use

   a. In line.

   b. Integral with aircraft.

7. Compactness

   Primarily length of load limiter.

8. Cost

   Primarily the unit cost.

Evaluation and Selection

For the evaluation, which is presented in Table XIV, each device was assigned a weighted value (with maximum of 10) for the pertinent items considered. The data is self-explanatory in that the highest assigned value is given the highest rating.

It appears from Table XIV that the tube-ball load limiter device offers the most advantages and has relatively few shortcomings. Therefore, the tube-ball device is selected as the energy absorber most adaptable for use in an integral helicopter restraint system (see Figures 114 through 117).

Alternate Uses of the Tube-Ball Energy Absorber

Alternate uses of the tube-ball energy absorber, other than those recommended, are:

Category I

As an add-on unit with a strap restraint device (replacing the AAE wire-bending units). As shown in Figure 42, AAE has designed and produced a tube-ball device for this application (see Reference 21).

Category II

As a variation of an add-on unit, requiring stowage and minor floor modification for attachment to the tiedown ring.

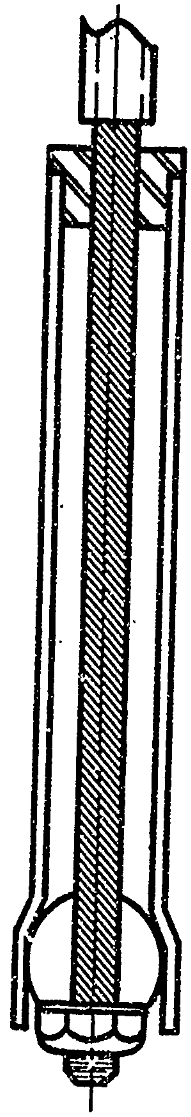


Figure 114. Tube-Ball Load Limiter Without Fittings.

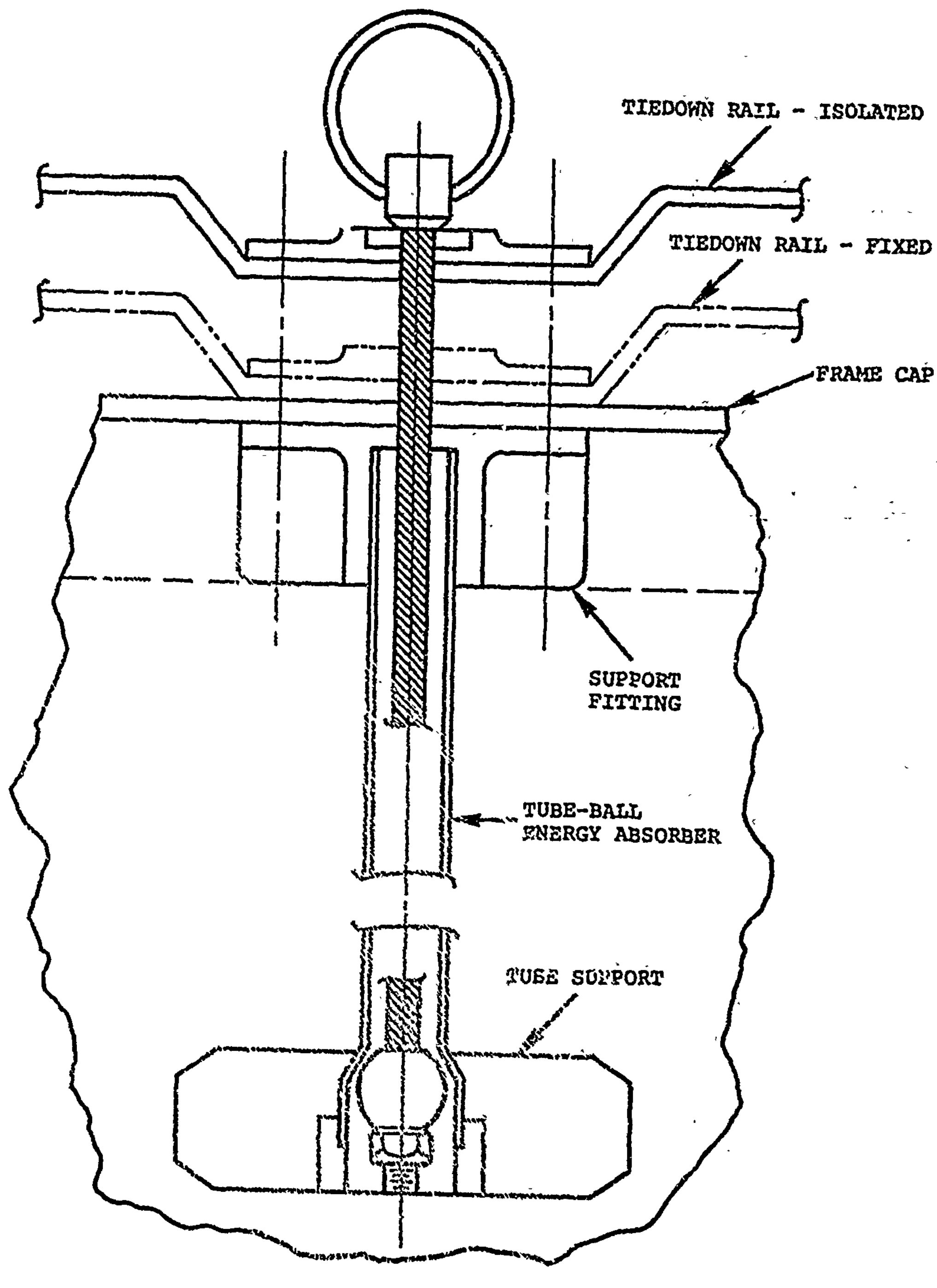


Figure 115. Tube-Ball Tiedown Energy Absorber (Typical Installation).

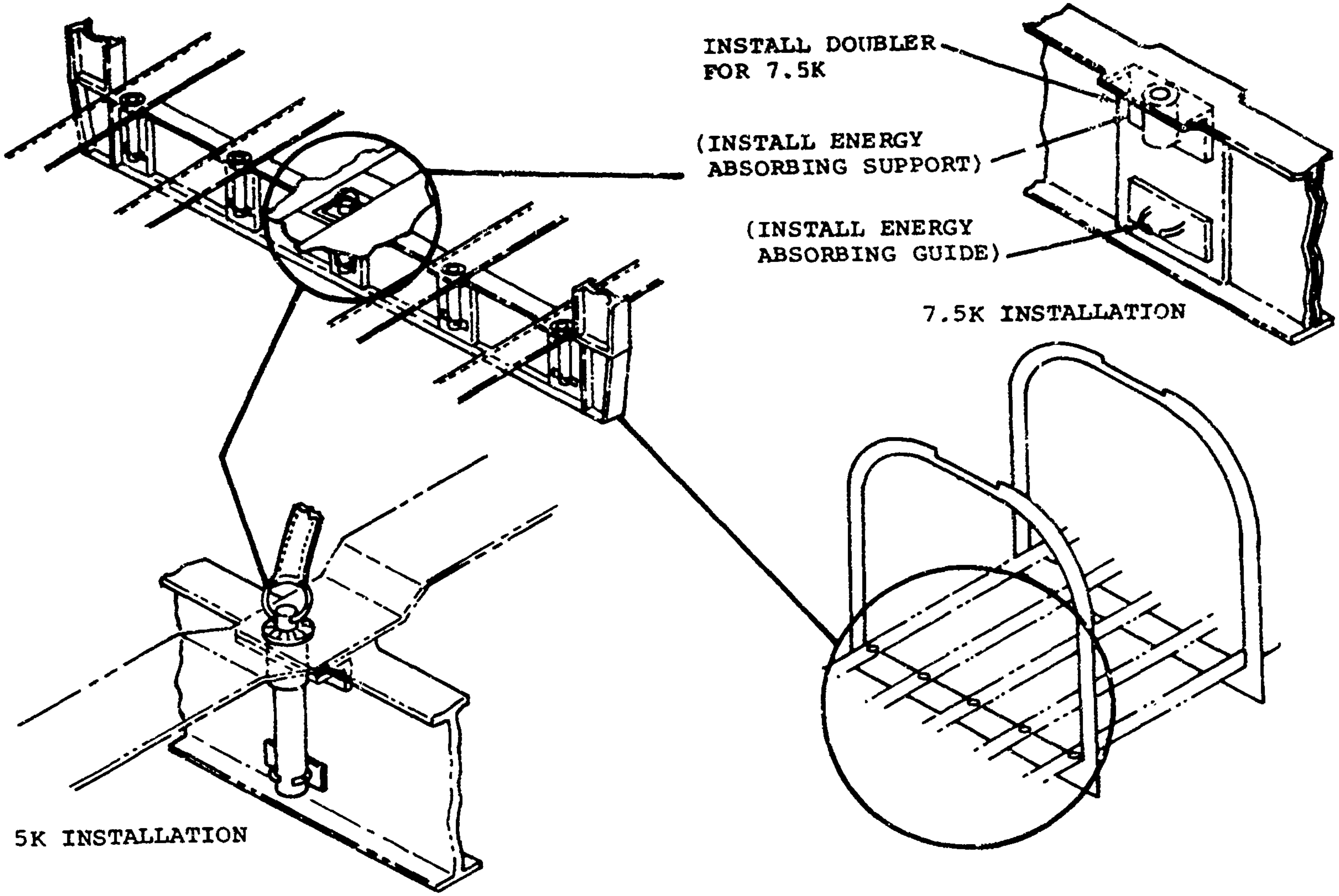


Figure 116. Typical 5K or 7.5K Tube-Ball Installation.

NOTES:
(1) AS AN ALTERNATE CH-47 INTEGRAL RETROFIT, ENERGY ABSORBERS ATTACH TO EXISTING TIEDOWN RING LOCATIONS.
(2) LOW-ELASTIC RESTRAINT TENSIONING DEVICES AND HOOK FITTINGS ARE USED.

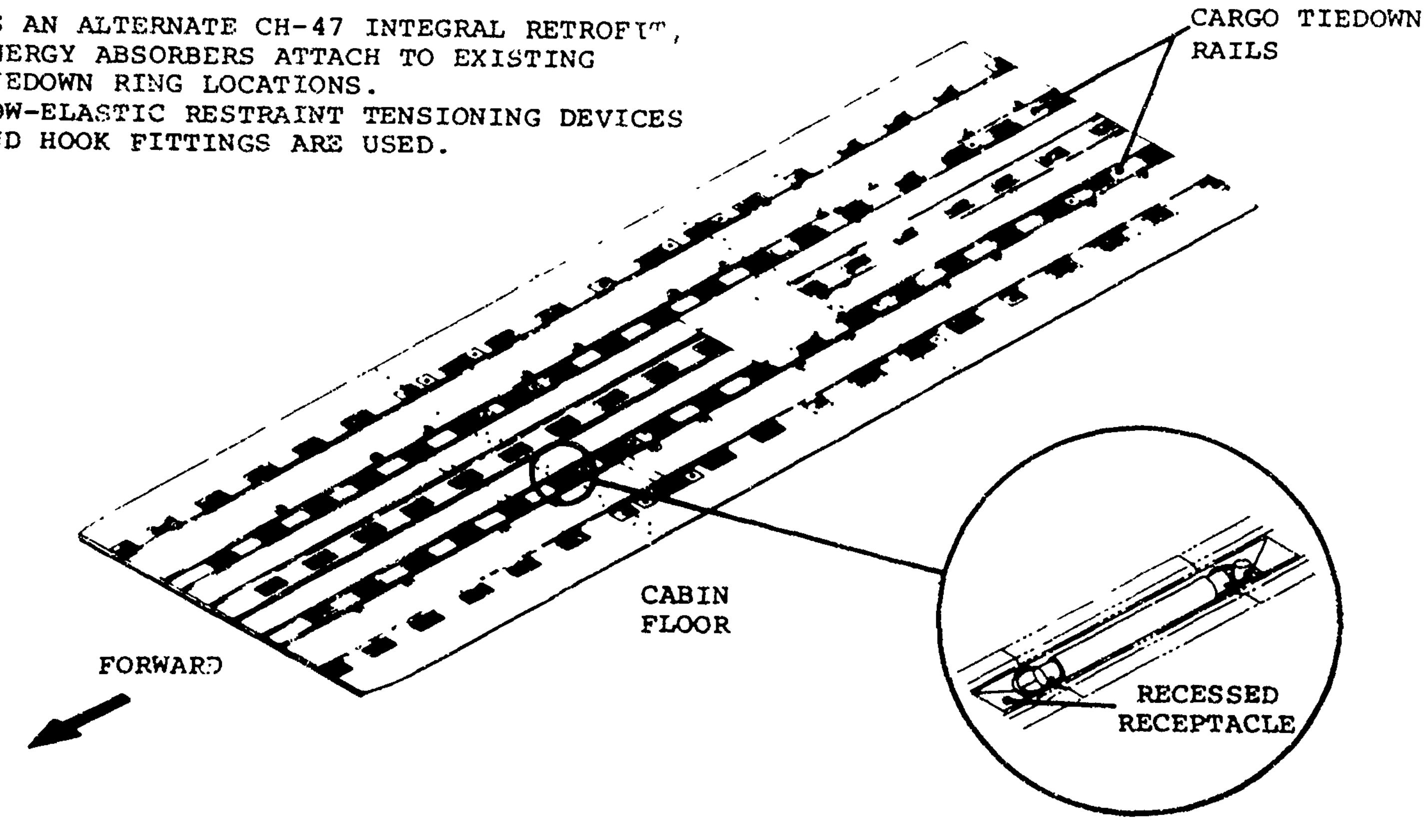


Figure 117. Alternate Use of Tube-Ball Energy Absorber Showing a Recessed Floor Installation.

TABLE XIV. EVALUATION OF CANDIDATE ENERGY ABSORBERS

Evaluation Items / Energy Absorbers*	Weighted Values (Maximum of 10 Per Item)								
	Weight	Development	Design Reqs	LL Dir	Efficiency	System Use	Compactness	Cost	Total Weighted Values
AAE Tube-Ball Design	8	10	9	10	10	10	9	9	75
AAE Wire Bending	6	10	7	8	10	10	8	5	64
Boeing Compression or Tension Peel Strut	8	7	7	8	6	10	8	5	59
VZA Metal Tube Bending	7	10	6.5	8	5	10	8	4	58.5
Accordion	8	0	7	10	8	10	10	5	58
VZA Model LL-3	6	7	4	8	8	10	8	5	56
ARDE Load Limiter	6	6	7	8	5	10	9	5	56
MRI Rolling Ring	8	5	6.5	8	6	10	5	3	51.5
Peck & Hale Shock Expander	4	2	5	10	6	10	7	7	51
Stainless Steel Strap	8.5	2	5	7	9	5	7	7	50.5
Split-Tube Tiedown	8	0	5.3	10	6	5	9	3	46.3
Aeroquip Split Tube	5	0	7	8	0	10	5	4	39

* Energy absorber devices not included in this table were not considered feasible.

In the Category I use, the tube-ball would be an improvement over the wire-through-platen units in size, weight, and cost. In lashing cargo, it would probably be more easily handled, due to its long cylindrical shape. However, the unit is subjected to environmental damage (such as a truck wheel driven over it). The degree of damage is a function of the cross-sectional shape and dimensions of the device. The tube-ball device, which has a tubular cover, is relatively more resistant to wheel loading than the plate type cover utilized with the wire-bending units. Also, stowage for these loose items must be provided. To solve the problems of stowage and loss of availability (common with loose components), a floor installation of the tube-ball can be made as shown in Figure 117.

In this configuration, one end of the tube-ball device would be designed as an integral part of the floor tiedown fitting. The device and fitting would be a single replaceable part. The other end of the device would include a tiedown ring for attachment to low-elastic restraints. When in use, this device would act in line with the restraint in the same manner as the AAE units. When not in use, these load limiters would be nested in a conforming floor pan in the tiedown rails which would include a detent, or snap lock (see Figure 117).

As an add-on alternative rather than an integral unit, the tube-ball has obvious advantages. First it is easily retrofittable, provided its load level is compatible with (equal to or less than) the capacity of the existing floor tiedown (i.e., a 5K unit with compatible restraints could be used with both 5K and 10K tiedown fittings in the CH-47 floor without airframe change). If its capacity must be higher (as dictated by reducing the number of restraints), then retrofit must also be accompanied by compatible airframe structural changes. As a line-replaceable unit, this design would be one of the simplest.

The lessons of Vietnam show that the alternate use would have disadvantages. It would be constantly and directly exposed to physical environment and human elements during all missions, whether or not it is in use. Also, if the units are not properly stowed, they may impede movement of cargo in or out of the aircraft, and would suffer physical damage from motor vehicles or movement of other massive objects. Since the units will receive no special care or attention, they must be extremely rugged and virtually indestructible. These latter qualities may result in an increase in weight and greater difficulty in handling.

7. EVALUATION OF SELECTED SYSTEM

7.1 DATA FOR SYSTEM EVALUATION

This section presents the basic data needed for the System Effectiveness Evaluation in Section 7.3. Included are the compilation of significant TOE internal cargo loads and their characteristics, cargo restraint and handling data, and the CH-47 aircraft mission selection.

CARGO LOAD SELECTION

The restraint systems to be compared during the mission effectiveness study are evaluated in terms of the same articles of cargo. For a realistic appraisal of the restraint requirements, the following ground rules were used:

1. External cargo-handling capability of the CH-47 was not considered in this study.

2. Cargo types representative of battalion equipment TO&E (Reference 44) were selected.

3. Restraint of load combinations was to illustrate the true difficulty experienced in meeting dynamic impulse requirements.

4. Very small loads were not considered, nor were bags of rice or other special items.

Most of the loads selected have been documented in published U.S. Army technical manuals (See Appendix III and References 45 through 50); also, loading and tiedown difficulties have been witnessed and reported by experienced Boeing field service representatives in Vietnam. Further background of these loads and tiedown procedures has been obtained by Boeing engineering representatives during visits to Vietnam. (See Appendix V.)

The Army equipment items selected for the restraint portion of the study are:

Class A - Miscellaneous Cargo (Small items less than 3 feet cubed)

1. U.S. Army wooden pallet (40 x 48 x 5-3/8 inches) loaded with 1,400 pounds of ammunition (equal to approximately 23 rounds of 105mm ammo or approximately 11 rounds of 155mm ammo, for the purpose of this study).

Class B - Homogeneous Cargo (Bulk items larger than 3 feet cubed)

1. M100 1/4-ton trailer
2. M151 1/4-ton truck
3. M100 1-1/2-ton 400-gallon water trailer
4. M37 3/4-ton truck
5. Standard 55-gallon POL drums (nonpalletized) in groups of four

Items excluded and the reasons for their exclusion are:

XM102 105mm Howitzer: Although the XM102 crew and ammunition fit within the CH-47 cabin, this item is usually carried externally. Gun movements are normally made between points where landings cannot be made.

M101 3/4-ton trailer: In general, similar to the 1/4-ton trailer general shape; it is between the 1/4-ton and 3/4-ton truck, when compared by weight.

M170 1/4-ton ambulance: Similar to the 1/4-ton truck in size and weight.

Further, none of the above items represent restraint problems more unique than those chosen for the study.

Physical characteristics of each of the items of cargo are given in Table XV. Load combinations for the mission effectiveness study are given in Table XVI. Load combinations for an idealized floor are given in Table XVII.

CARGO LOAD CHARACTERISTICS

Army equipment characteristics obtained from the documents listed in Appendix III are summarized in Table XV. This information was used in determining the load tiedown arrangement of each load, proper cg location, clearance requirements, and residual troop seating capacity.

Combinations of these articles of cargo were also made for the mission effectiveness study. The various cargo load types assembled included vehicles, pallets or POL, and troops. The loads shown in Table XVI were specifically combined to illustrate the range of restraint problems encountered in the field. Each load type was limited to items which could be restrained to a 90th percentile of survivability for comparison of the different restraint systems.

The two cargo load groups listed "CH-47" and "Idealized Floor" serve to provide a basis of restraint survivability comparison which could not otherwise be established. (This comparison is

TABLE XV. TOE LOAD CHARACTERISTICS						
Vehicle	Length (in.)	Width (in.)	Height (in.)	Weight (lb)	Position Facing	Restraint Ref Pt
M151 truck	132	64	53	2,350	Aft	Front Axle
M100 trailer or	108	57	43	1,090*	Aft	Axle
M416 trailer** and	109	62	43	1,800*	Aft	Axle
M151 Truck TM55-2320-218-10-3	132	64	53	2,350	Aft	Front Axle
M170 1/4-ton ambulance TM55-2320-208-10-1	155	61	80+	2,963	Aft	Front Axle
M37 3/4-ton truck and	186	75	65	5,660	Aft	Rear Axle
M107 1-1/2-ton water trailer (400 gal) TM55-2300-201-10-1	164	82	77	2,260	Aft	Axle
M37 3/4-ton truck	186	74	66	5,687	Aft	Front Axle
M101 3/4-ton trailer TM55-2320-212-10-2	147	74	65	1,340	Aft	Axle
M151 1/4-ton truck and	132	63	53	2,350	Aft	Front Axle
M100 1/4-ton trailer TM55-2320-218-10-2	108	57	43	1,090*	Aft	Axle
M38 A1C (w/106mm) 1/4-ton truck (recoilless)	152	68	71	3,220	Aft	Rear Axle
M151 A1C (same as above) TM55-1000-205-20-1	148	72	64	3,235	Aft	Rear Axle
40-in. x 48-in. U.S. Army pallet 105mm ammo (equals 23 rounds)	44	52	54	1,400	48-in. Fwd/ Aft	None
Group of four 55-gal drums (POL)++	44	44	34	1,436	Any	None

* Includes 500 pounds of cargo secured in trailer.
** Alternative to M100.
\+ Reduced height before loading.
++ One 55-gal. drum: 22-inch diameter by 34-inch height, weighing 359 pounds.

TABLE XVI. LOAD COMBINATIONS USED WITH CH-47 FLOOR

CARGO LOAD TYPE	ITEMS OF CARGO	CARGO WEIGHT (lb)	PAYLOAD PER SORTIE (lb)
A-1	1 M151 1/4-ton truck	2,350	
	1 40-in. x 48-in. pallet (Ammo)	1,400	
	10 troops @ 240 lb ea	2,400	
	2 gunners @ 240 lb ea	480	
			6,630
A-2	1 M151 1/4-ton truck	2,350	
	1 M100 1/4-ton trailer	1,090	
	8 troops @ 240 lb ea	1,920	
	2 gunners @ 240 lb ea	480	
			5,840
A-3	1 M107 1-1/2-ton water trailer	2,280	
	1 40-in. x 48-in. pallet (Ammo)	1,400	
	12 troops @ 240 lb ea	2,880	
	2 gunners @ 240 lb ea	480	
			7,040
A-4	1 M107 1-1/2-ton water trailer	2,280	
	4 55-gal drums @ 359 lb ea	1,436	
	12 troops @ 240 lb ea	2,880	
	2 gunners @ 240 lb ea	480	
			7,076
A-5	12 55-gal drums @ 359 lb ea	4,308	
	20 troops @ 240 lb ea	4,800	
	2 gunners @ 240 lb ea	480	
			9,588
A-6	1 M151 1/4-ton truck	2,350	
	16 troops @ 240 lb ea	3,840	
	2 gunners @ 240 lb ea	480	
			6,670
A-7	1 M37 3/4-ton truck	5,660	
	10 troops @ 240 lb ea	2,400	
	2 gunners @ 240 lb ea	480	
			8,540
A-8	1 M107 1-1/2-ton water trailer	2,280	
	20 troops @ 240 lb ea	4,800	
	2 gunners @ 240 lb ea	480	
			7,560

TABLE XVI - Continued

CARGO LOAD TYPE	ITEMS OF CARGO	CARGO WEIGHT (lb)	PAYLOAD PER SORTIE (lb)
A-9	3 40-in. x 48-in. pallets (Ammo) @ 1400 lb ea	4,200	
	8 troops @ 240 lb ea	1,920	
	2 gunners @ 240 lb ea	480	
			6,600
A-10	1 3/4-ton trailer internal	1,340	
	20 troops @ 240 lb ea	4,800	
	2 gunners @ 240 lb ea	480	
			6,620

TABLE XVII. LOAD COMBINATIONS USED WITH IDEALIZED FLOOR

CARGO LOAD TYPE	ITEMS OF CARGO	CARGO WEIGHT (lb)	PAYLOAD PER SORTIE (lb)
B-1	2 M151 1/4-ton trucks	4,700	
	1 M100 1/4-ton trailer	1,090	
			5,790
B-2	1 M151 1/4-ton truck	2,350	
	1 M100 1/4-ton trailer	1,090	
	1 M107 1-1/2-ton water trailer	2,280	
	1 40-in. x 48-in. pallet (Ammo)	1,400	
			7,120
B-3	1 M151 1/4-ton truck	2,350	
	1 M100 1/4-ton trailer	1,090	
	2 40-in. x 48-in. pallets (Ammo)	2,800	
			6,240
B-4	1 M151 1/4-ton truck	2,350	
	1 M100 1/4-ton trailer	1,090	
	8 55-gal drums @ 359 lb ea	2,872	
			6,312
B-5	1 M151 1/4-ton truck	2,350	
	1 M100 1/4-ton trailer	1,090	
	1 40-in. x 48-in. pallet (Ammo)	1,400	
	4 55-gal drums @ 350 lb ea	1,436	
			6,276
B-6	12 55-gal drums @ 359 lb ea	4,308	
			4,308

further discussed in Section 7.3.) Therefore, no attempt was made to achieve a full 11,400-pound payload for each sortie, since it would serve no purpose in this study. Limitations in the carrying of troops as cargo were predicated on the following definition of seat availability:

1. Usable seats (where seat and cargo clearance permit). Assume all seats single and outside the load-stroke envelope.

2. No seating on the floor.

3. Two gunners included in each CH-47 sortie.

4. Crew chief is located in the jump seat.

5. Twenty-inch seat spacing used.

6. Eight-inch movement clearance maintained around cargo.

CH-47 INTERNAL CARGO FEATURES

The aircraft selected as the basis of the cargo restraint study was the U.S. Army Standard Chinook CH-47A medium transport helicopter. The Chinook has a three-man crew (pilot, copilot, and crew chief) and two gunner stations. The rotors are powered by two T55-L-7C Lycoming gas turbine engines.

The primary tactical mission of the model CH-47 helicopter is to provide air transportation for cargo, troops, and weapons within the combat area and to perform special support functions.

The original design objective used to determine the cabin size was the accommodation of all the components of the Pershing missile system. Details of the cabin for cargo handling and restraint provided for this application are as follows:

1. The cabin has an unobstructed length of 362 inches, a cross-section width of 90 inches, and a height of 78 inches. The cabin floor is provided with a cargo tie-down ring pattern approximately 20 inches square.

2. A hatch is provided in the center of the cabin floor with a dual-purpose cargo/rescue winch for the alternate capability of discharging or loading small, light cargo items, or for rescue. In the cargo mode of operation, the winch is capable of moving larger cargo loads, including vehicles, in and out of the aircraft via the rear loading ramp. The CH-47 cargo restraint fittings are shown in Figure 11. They

were designed to fixed ultimate loads based on steady load requirements before development of dynamic tiedown criteria (Reference 2). New floor fitting design should be based on dynamic load level (crash pulse) criteria (Reference 1), and, if possible, the airframe substructure should be designed to attenuate floor crash impulses.

3. Figure 96 illustrates the CH-47 cargo restraint system, the tiedown devices provided onboard the aircraft, and their cabin cargo tiedown pattern.

Items furnished by the Army as flyaway equipment are as follows:

FSN	Type	Description	Quantity
1670-545-9062	MB-1	Chain Tiedown 10K Capacity	8
1670-725-1437	MC-1 or CGV-1/B	Tiedown Strap (Nylon) 5K Capacity	32

INTERNAL CARGO MISSION PROFILE

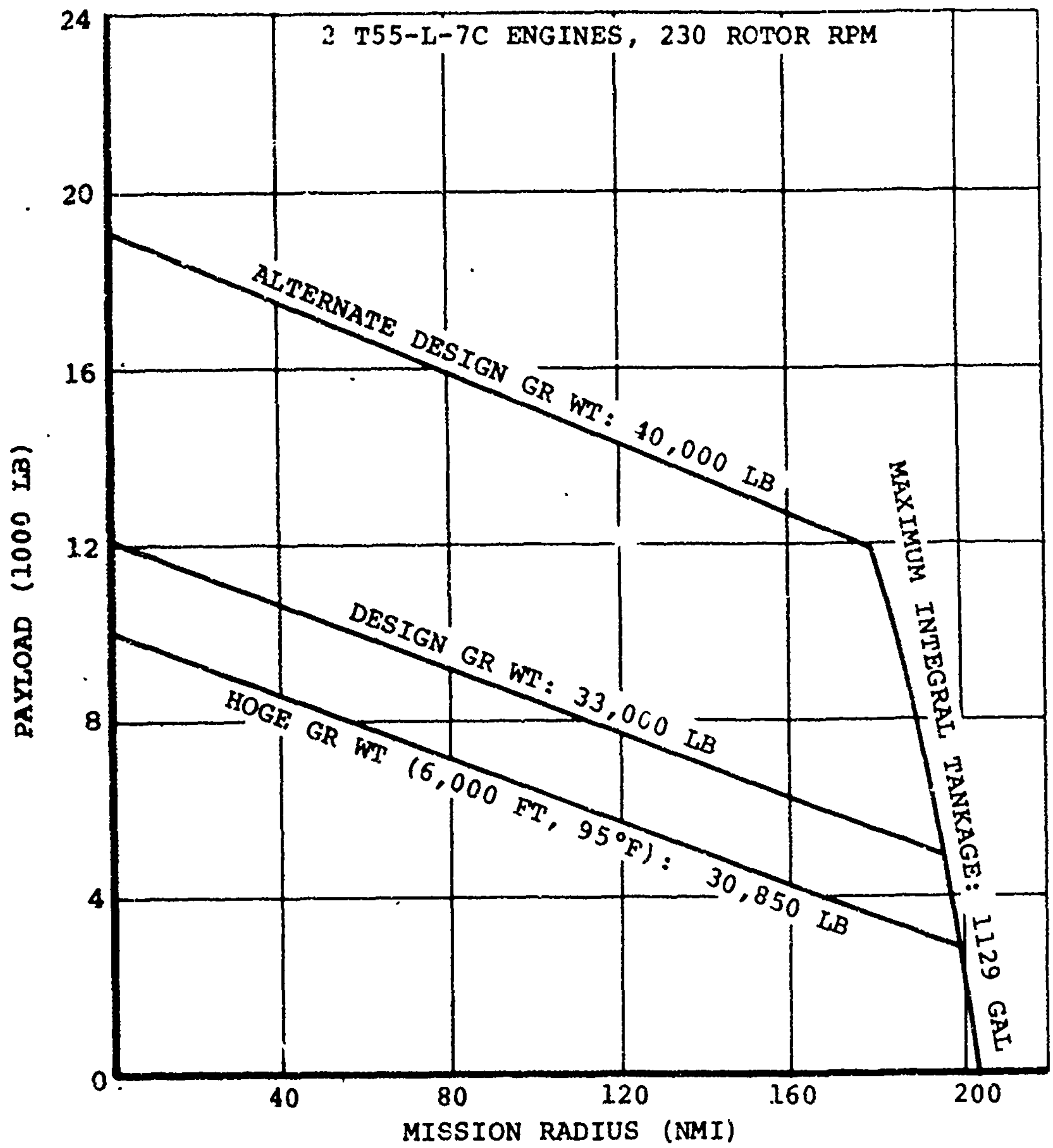
The mission chosen for the study is one of short range, but is typical of the average resupply operation. It was selected to increase the sensitivity to cargo restraint time (and handling time) and to permit a single basis for the evaluation of the various restraint system studies.

Mission III basic performance data as specified in report 114-PJ-702A, Revision B, is used.

The mission, depicted graphically in Figure 118, is as follows:

Mission radius	20 nautical miles
Design gross weight	33,000 pounds
Payload	11,400 pounds
Warm-up	2 minutes at normal power (230 rotor rpm)
Takeoff and cruise	Outbound
Land	Unload payload
Warm-up	2 minutes at normal power
Takeoff and cruise	Inbound
Land	10 percent fuel reserve

With this basic mission capability, the mission profile is further defined in the methodology analysis for the various restraint systems (see Section 7.2).



MISSION DESCRIPTION

1. WARM UP 2 MIN AT NP
2. TAKE OFF AND CRUISE OUTBOUND
3. LAND
4. WARM UP 2 MIN AT NP
5. TAKE OFF AND CRUISE INBOUND
6. LAND WITH 10% FUEL RESERVE

NOTES:

(1) CRUISE AT 99% OPT RANGE SPEED
(2) WEIGHT EMPTY: 20,861 LB
(3) FIXED USEFUL LOAD: 739 LB

CREW (3)	600
UNUSABLE FUEL	36
OIL	25
ENGINE OIL	28
TIEDOWNS	50
	739 LB

Figure 118. Internal Cargo Payload Capability of CH-47C Helicopter.

CARGO LOADING

Rapid cargo loading is a basic need in the field. Douglas (Reference 10) has made a study and has recommended improvements to the cost-effectiveness of CH-47 cargo loading. However, improvements in cargo handling, loading, or unloading efficiency, per se, are not a part of the present investigation. Cargo handling was treated as a nonvariable, unaffected by the type of restraint system used. Therefore, variations in cargo handling time are attributable to the differences in cargo restraint equipment techniques.

Chapter 13 of the CH-47 Operator's Manual provides cargo loading information for the existing aircraft. For purposes of this study, these procedures are assumed to have been followed, except for palletized cargo. In the case of palletized cargo, it is assumed that rapid ramp loading and unloading capability exists, and that each aircraft is equipped with lightweight stowable roller assemblies, as pictured in Figure 15. This system is feasible and meets the requirements for automation considered in the Douglas report.

Further assumptions were that Class B vehicular cargo is loaded by manpower or driven (backed) into the aircraft, and that ample manpower is available, as required. The loading time for the representative pallet load is estimated, and includes the use of roller conveyors. The time estimate for the 55-gallon drums is based on rolling the drums into the aircraft without the use of roller conveyors.

Load and unload times used in this study were made available by the Army in the form of the technical manuals described in Appendix III. Handling times for pallets, POL, and ammunition were obtained from Boeing field representatives. Table XVIII summarizes the basic cargo loading times obtained from these sources.

Positioning of the loads for restraint in the CH-47 cabin required consideration of available tiedown locations and aircraft cg location. Figure 119 gives the CH-47C cargo loading cg envelope used. Accordingly, loads were located between 21.3 inches forward and 7.0 inches aft of the aircraft datum line for 33,000 pounds gross weight.

CARGO RESTRAINT PRACTICE

U.S. Army Technical Manual Requirements

Tiedown requirements for internal cargo vary from aircraft to aircraft, and are usually detailed in the specific operations or supplementary handbook.

TABLE XVIII. CARGO LOADING TIMES USING PRESENT ARMY METHODS

Vehicles	Time to Prepare, Load, and Tie Down (min)	No. of Men Reqd	Time to Release and Unload (min)	No. of Men Reqd	Total Time to Load and Unload (min)
M151 Truck					
M100 Trailer or M416 Trailer (Alt) and M151 Truck	30	4	20	4	50
M170 1/4-ton Ambulance	20	3	10	3	30
M37 3/4-ton Truck and M107 1 1/2-ton Water Trailer (400 gal)	30	4	15	4	45
M37 3/4-ton Truck					
M101 3/4-ton Trailer	30	3	15	3	45
M151 1/4-ton Truck and M100 1/4-ton Trailer	25	3	20	3	45
M38 A7C 1/4-ton Truck (w/recoilless 106mm), or M151 A1C	20	4	10	4	30
(1) 40- x 48-in. U.S. Army Pallet 105mm Ammo (representative load)	2.5	4	2.5	4	5
12 55-Gal Drums POL	10.5	4	10.5	4	21

See technical manuals listed in Appendix III.

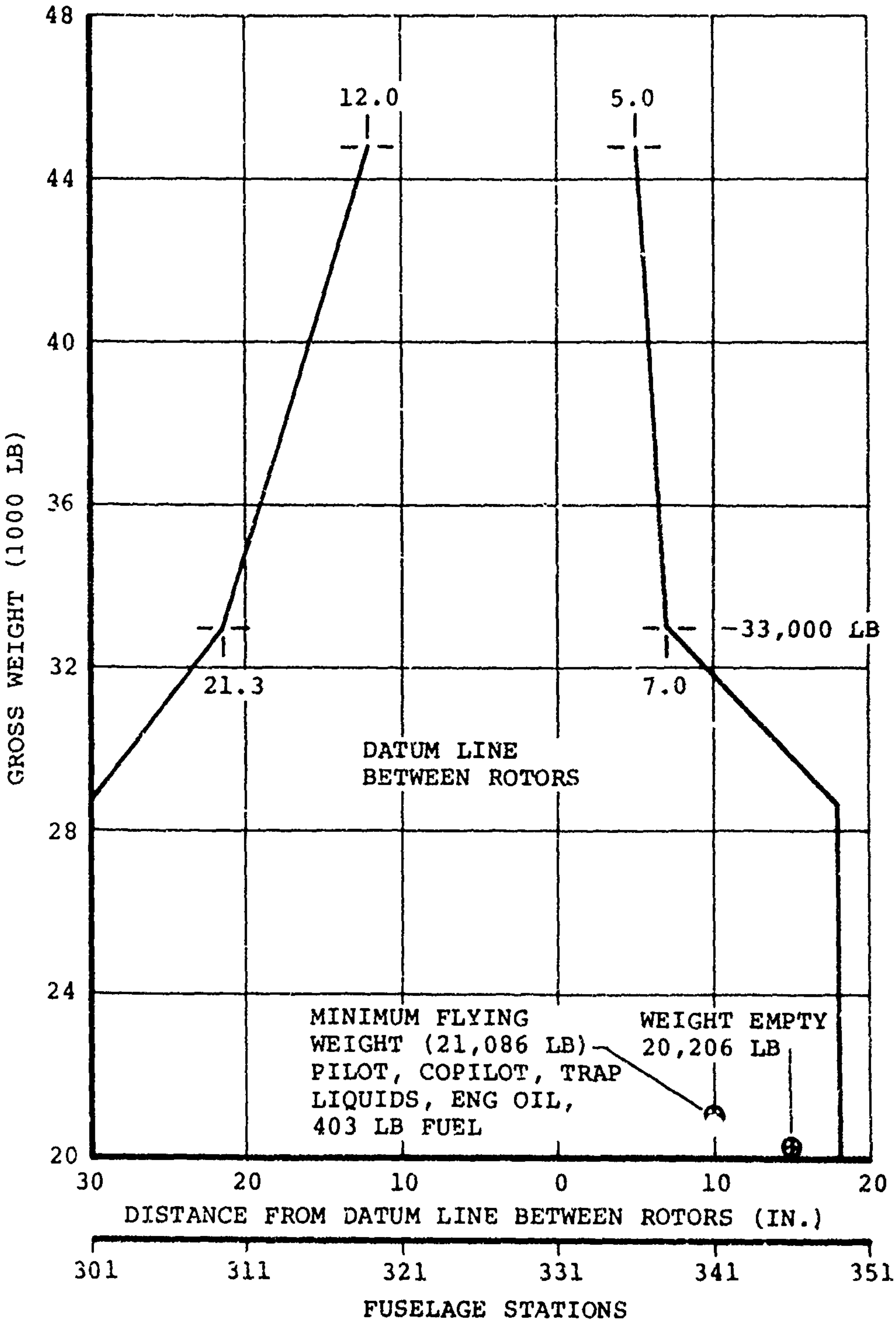


Figure 119. CH-47C Cargo Loading CG Envelope.

The CH-47 Operator's Manual, Army Model CH-47 Helicopter, TM 55-1520-227-10, Section III, Aircraft and Personnel/Cargo for Loading and Unloading, and Section IV, General Instructions for Loading, Securing, and Unloading Cargo, gives general instructions for equipment usage and securing of cargo to a static g level for the CH-47 helicopter. AR 705-35 also specifies the following static criteria for cargo and personnel:

Tiedown Direction	Restraint Criteria in g's
Forward	4.0
Aft	2.0
Down	4.0
Up	2.0
Lateral	1.5

Specific tiedown instructions for certain vehicles transported internally in the CH-47 helicopter are noted in Appendix III.

Administrative Missions

Reasonable adherence to required security of internal cargo is exercised by the U.S. Army in operations where there is sufficient loading, restraint, release and unloading time (such as within the continental United States), or when non-combat-area supply or administrative flights are being made. However, Army investigations (Reference 2) and contractor studies (Reference 21) for the Army have indicated that these restraints are inadequate for crash safety. Present practices, while exceeding flight restraint requirements, are grossly insufficient for crash-load retention. Also, they are too time consuming for the reaction time required for rapid cargo handling.

Combat Missions

Too often the GI in combat ignores statements in the technical manual such as: "Warning - transport of the M151 1/4-ton truck and M100 1/4-ton trailer in the CH-47 helicopter is prohibited if the item is not loaded and tied down in accordance with the instructions in this manual." Combat crews in the field are of the opinion that an accident won't happen to them, that proper cargo tiedown (and release) causes excessive exposure to the enemy when under fire, and that if they do crash they don't have a chance anyway. They do not relate cargo restraint to crash safety.

Consequently, little, if any, cargo restraint is utilized when flying into and out of the landing zone. This reasoning on the part of the combat serviceman has developed despite the handbook instructions (Reference 3) which specifically state that the restraints are for the prevention of cargo shifting

in the event of violent or sudden maneuvers or a crash. The handbook (Chapter 13, Section IV) states:

> "The helicopter is subjected to forces which result from air turbulence, acceleration, rough or crash landings, and aerial maneuvers. These same forces act upon the cargo in the helicopter and tend to shift the cargo unless it is firmly secured. Forward motion of the helicopter is the most rapid movement that will be encountered, and since the cargo moves at the same rate of speed as the helicopter, forward movement is the strongest force that is likely to act on the cargo if the helicopter is suddenly slowed or stopped in a crash landing. Other forces tending to shift the cargo aft, laterally, or vertically will be less severe. The amount of restraint required to keep the cargo from moving in any direction is expressed in units of the force of gravity, or g's. In each case, the maximum force exerted by the item of cargo to be restrained would be its normal weight times the number of g's of the restraint criteria. In order to carry cargo safely, the amount of restraint supplied should equal or exceed the maximum amount of restraint required."

Restraints patterns used in this study were based wholly on dynamic restraint requirements. The static tiedown practices, as shown in Appendixes III and IV, were also used for estimating comparative survivability under both static and dynamic restraint conditions. These comparisons are made in Section 7.4.

Cargo Restraint Time Data

Data concerning the time it takes to restrain and release cargo transported internally in a CH-47 has been difficult to obtain. A search for this information was implemented with distribution of a questionnaire to Boeing field service representatives at various U.S. Army installations. (See Appendix IV.) Attempts to obtain this information during Army field exercises were made by contacting Boeing representatives at Forts Bragg, Benning, Sill, and Rucker. Contact with USAAVLABS resulted in obtaining information on several vehicles. Basic restraint details were lacking, however, in that the times given are lumped together and include load preparation, loading, restraint and unloading.

The information used for this study was based on the data obtained from instructors at Fort Sill who had operating experience in Vietnam, while information received from the field is presented in Appendix IV. Table XIX shows the detailed time data used. Total loading and unloading times were fixed from the technical manual data obtained from References 45 through 50, from which Appendix III restraints were also obtained. Where

TABLE XIX. CARGO UNIT AND RESTRAINT DEVICE TIEDOWN TIMES

Cargo Unit	Reported Tiedown Time (min)	Estimated No. of Devices	Time per Device (min)
1/4-ton truck	3	4 chains or straps	0.75
1/4-ton trailer	1	3 straps	0.33
1/4-ton truck 1/4-ton trailer	5	7 chains and/or straps	0.71
3/4-ton truck	5	6 chains	0.83
3/4-ton trailer	1-1/2	3 straps	0.5
3/4-ton truck 3/4-ton trailer	6-1/2	9 { 6 chains 2 chains and 1 strap	0.72
POL drums	5	10 straps	0.5
105mm ammo pallet	3	6 straps per pallet	0.5
M107 water trailer	1-1/2	3 { 2 chains and 1 strap	0.5

no data were forthcoming from the field, assumptions were made based on discussions with Boeing field representatives.

These items include placing and tightening the restraint. With no specific release times available, it was assumed for the study that release and restraint times would be equal. Therefore, variation in total system restraint and release times would vary principally because of tiedown time. (If quick-release hardware were available in the field, release times would be shorter.)

For this evaluation, the restraint and release times established were considered applicable and were included in the technical manual data on cargo handling (References 45 through 50).

Restraint Practice in Vietnam

Recent photographs from Vietnam have documented the prevailing, accepted cargo restraint practices previously reported by Boeing field service representatives. The following examples typify some of the conditions observed for a variety of internal loads and show the need for an effective educational program on crash restraint and safety:

1. Figure 120 shows a load of lumber with two straps tied laterally over the load, with men sitting unrestrained either on top, in front, or behind the load. Here, restraint is insufficient except to keep cargo from sliding sideward in flight maneuvers.

2. Figure 121 shows a gunner sitting on an unrestrained water container. (Other examples show bar stools and ammunition boxes used for seats. Personnel do not seem to realize that these loose items are potential missiles in the event of a crash.)

3. Figure 122 shows evacuees squeezed in alongside bags of rice which are piled together, but are essentially unrestrained. (Crew members sit astride cargo, showing little awareness of restraint requirements.)

4. Figure 123 shows palletized loads including vegetables in broken crates which are combined somewhat haphazardly with other miscellaneous cargo. There are broken bands on some cargo packages, which are then restrained only by two nylon straps against fore and aft movement during flight.

Use of Cargo Nets in Restraint Systems

Nets, for purposes of this study, were considered a restraint component of specific but limited application. Their main advantage would be to secure loose objects and bulk or palletized cargo. In the Load Selection paragraph it was stated that small items of cargo would not be included in the load array. These were eliminated since the effectiveness of an energy-absorbing restraint system could be adequately shown using a mix of vehicles, pallets, and POL; and the use of nets would not contribute materially in distinguishing between them. Since restraint time is the comparative factor involved in this study, and for purposes of consistency, strap restraints were used throughout the study for all systems.

This viewpoint appears confirmed from observation of recent tests of available (nonproduction) nets with quick-tiedown and -release features at Quantico Marine Base, HMX-1 (see Figure

Figure 120. Shipment of Personnel and Gear, Lumber, and Supplies in a CH-47 (Vietnam, August 1968).

Figure 121. Unrestrained and Partly Restrained Articles in a CH-47 (Vietnam, August 1968).

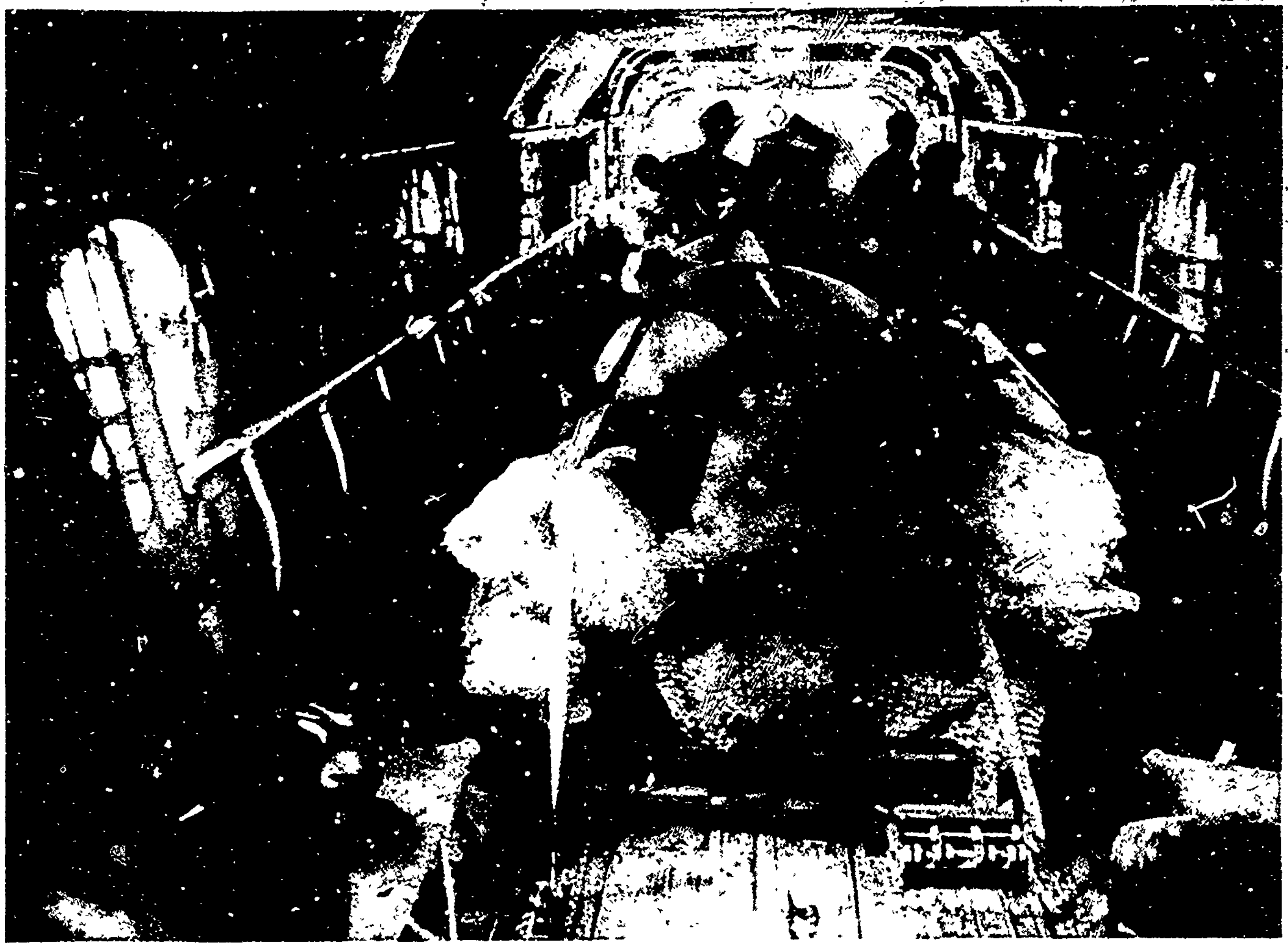


Figure 122. Transport of Passengers and Partially Restrained Cargo on Pallets and Rollers (Vietnam, August 1968).

Figure 123. Securing Palletized Cargo on an Improvised Roller System in a CH-47 (Vietnam, August 1968).

14). In these tests, three pallets were secured with standard restraints. Observed tiedown times were as follows:

	Restraints	Men		Minutes		Man/Minutes
1st trial	18	3	x	10	=	30
2nd trial (straps pre-positioned)	18	2	x	5	=	10

This effort was of the same order as restraint by the use of straps; consequently, from these tests it was concluded that the nets, in themselves, could not be expected to significantly reduce the restraint or release times.

7.2 SYSTEM EFFECTIVENESS METHODOLOGY

GENERAL

The addition of a cargo restraining subsystem to an existing or proposed air transport system may influence the mission effectiveness and/or subsequent cost effectiveness of that system. The purpose of this analysis is to determine quantitatively the relative effectiveness impact each candidate cargo-restraining subsystem has on total mission effectiveness, in terms of an effectiveness index. These indices, together with the relative cost of each modified air transport system, will be combined into a cost-effectiveness index for each candidate cargo restraining subsystem.

Qualitative as well as quantitative factors should be considered in evaluating the relative worth of each candidate subsystem. The quantitative factors can be reflected in the effectiveness analysis and/or the cost analysis. For use in this study, design complexity is defined in relation to maintenance and R&D costs. A design considered highly complex will subsequently require higher maintenance and development costs than another less complex system. The cost components reflecting these factors are included in the mission cost-effectiveness analysis. Similarly, system weight, cost, cargo operations, and aircraft performance, as they relate to each specific system, are factors affecting the mission cost-effectiveness analysis. These quantifiable factors will also be listed independently, for comparative purposes. The qualitative factors which, in general, cannot be integrated into the analysis when presented separately may serve to differentiate between subsystems having nearly identical cost-effectiveness indices. Each system will be qualitatively evaluated with respect to its compliance with design objectives (e.g., component integral installation, minimum required number of cargo tiedown devices, rapid and simple rigging and derigging of cargo, minimum component weights with design sturdiness, retention of cargo during relatively excessive airframe distortion, system redundancy, suitability for

retrofitting into current aircraft and applicability to new helicopter design). The flow diagram shown in Figure 124 depicts the functional relationships of the major events in the analysis leading to the desired relative cost-effectiveness index.

The methodology is used for the System Effectiveness Evaluation presented in Section 7.3, and a sample computation is presented in Appendix VI.

EFFECTIVENESS METHODOLOGY

The primary measure of effectiveness in this analysis is the number of aircraft (equipped with candidate cargo restraint subsystems) required to complete the mission in one operating day. The cargo type and quantity will be defined in terms of a mission requirement: namely, the transfer of a specified Airmobile (TOE) plus X number of days resupply. Since the operation is to be completed in one operating day, the retrograde cargo will be limited to medical evacuation and therefore will not impact the cargo loading times.

The effectiveness analysis will assess the effect of installing cargo restraint systems on a CH-47 air transport system. The analysis will concentrate primarily on the change in aircraft parameters and/or cargo handling parameters generated by the addition of these subsystems.

The ultimate impact of the addition of cargo restraint subsystems on other parameters, such as crew survivability, cargo type, cargo weight and dimensions, aircraft delivery mode (taxi/drop) and time available for other missions, is beyond the scope of this analysis.

ESSENTIAL CARGO RESTRAINT SUBSYSTEM ELEMENTS FOR ANALYSIS

Payload degradation (i.e., the loss in payload due to the installation of the cargo restraint system and the time to load, tie down, release, and unload a specified cargo load) affects the productivity of the total air transport delivery system. Cabin compatibility, the changes in the aircraft structural design, is reflected in the cost and may be a qualitative factor if volume ic constraints arise as a direct result of the installation of a particular cargo restraint subsystem.

Cargo Load Composition

The selected Airmobile TOE will be loaded as realistically as possible, providing a combination of mixed loads (loads with different types of cargo) and homogeneous loads (loads with a single cargo type). The primary considerations in the loading rationals will be tactical integrity and load factor (percent

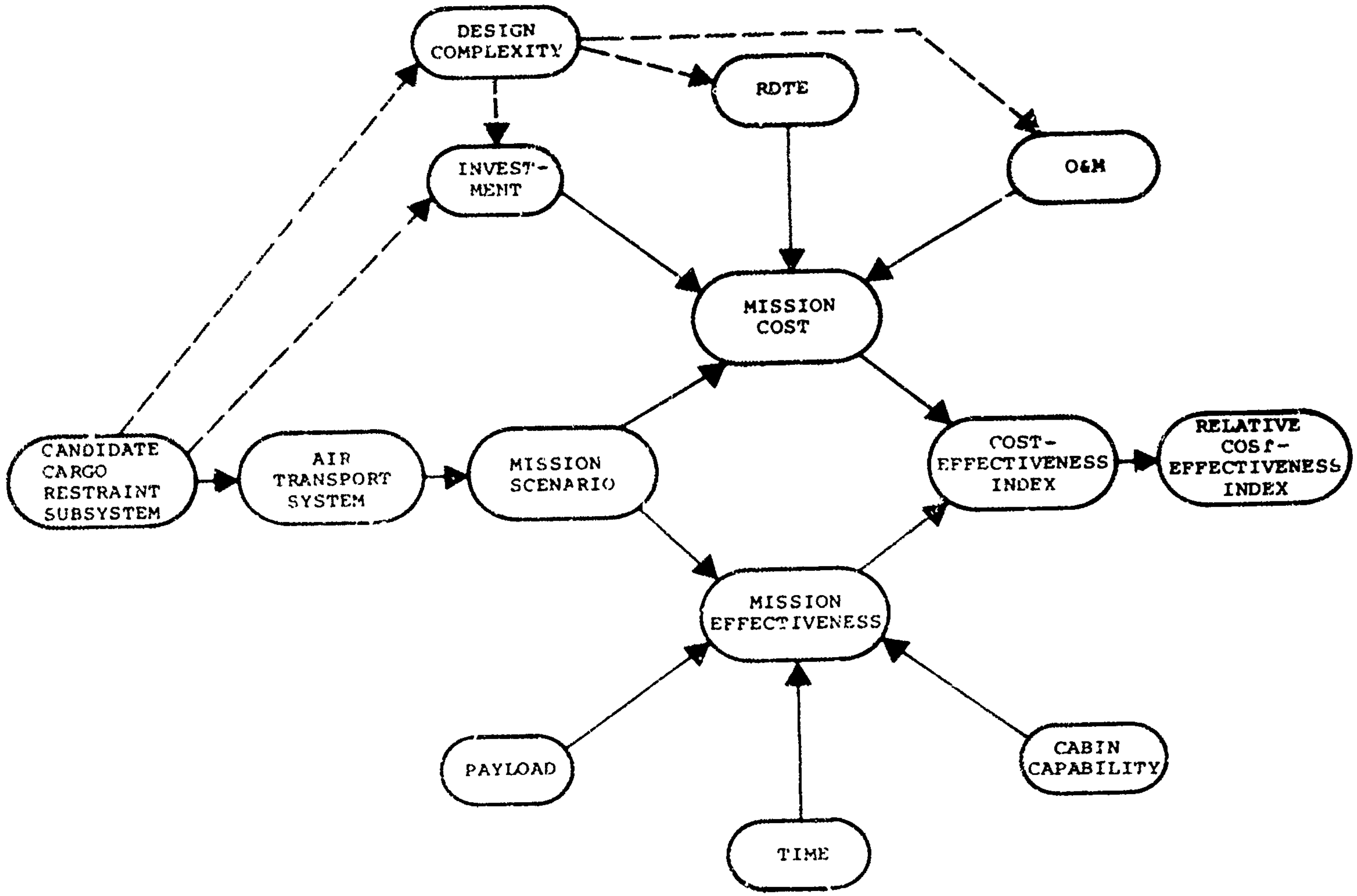


Figure 124. Flow Diagram of System Effectiveness Evaluation.

of available payload utilized), in that order of precedence, for the initial phase. In the resupply phase, the primary consideration is simply maximizing the load factor. To simplify the problem, a set of specifically defined loads will be synthesized from the prescribed TOE and utilized to evaluate each candidate subsystem.

Cargo Handling Operations

Total cargo handling time consists of the time to load, restrain, release and unload cargo. The restraint and release times will be calculated for each aircraft load, thereby reflecting the operating characteristics of each selected candidate cargo restraint subsystem.

Loading and unloading times are parameters of mission cycle time. For the shorter radii missions, these parameters are a significant portion of mission cycle time. The reduction of these times will show the greatest increase in aircraft productivity at the shorter radii, although some increase in productivity will be evident at all radii.

Operating Day

The operating day concept for a 24-hour period is divided into two time periods: productive and nonproductive time. Nonproductive time is that time when the aircraft system cannot be operated for some reason, usually VFR limitations. This time is generally available for the performance of scheduled maintenance. Productive time is divided into two periods: flight time and ground time.

Flight time consists of actual use of the aircraft; on a helicopter, this is generally accepted as the time when the rotors are turning. Ground time consists of:

1. Loading and unloading times
    a. Tiedown time
    b. Release time
2. Fueling time
3. Unscheduled maintenance time
4. Inspection time
    a. Preflight
    b. Post flight

Effectiveness Parameters Defined

T_{Cr} = Outbound average cruise time for a specified mission radius.

T_d = Time to taxi, take off, climb in and out of formation.

T_f = Fueling time; fueling philosophy being that the aircraft fuel, after a specified number of sorties, is dependent on mission radius at a location adjacent to the loading area.

TT_{ij} = Tiedown time for the i-th unit of the j-th cargo type.

TR_{ij} = Release time for the i-th unit of the j-th cargo type.

TL_{ij} = Loading time for the i-th unit of the j-th cargo type.

TU_{ij} = Unloading time for the i-th unit of the j-th cargo type.

S_r = Total number of sorties required to complete the lift determined by the loading exercise, and the payload capability of an aircraft for the radius specified.

TU_m = Unscheduled maintenance time (hours per flight hour).

n_j = The number of units of j-type cargo.

N_r = The number of trips per full fuel load for the r-th radius.

FT_r = Total flight time required to complete the specified lift.

PT = Available productive time per aircraft for one operating day; generally accepted as 12 hours.

GT = Total ground time required to complete the lift.

No. A/C = Number of aircraft required to complete the lift in one operating day.

Measure of Effectiveness

The measure of effectiveness is simply the number of aircraft required to complete the lift in one operating day.

$$FT_r = (T_{Cr} + T_d)\ S_r \qquad (30)$$

$$GT = T_f \left(\frac{S_r}{N_r}\right) + \sum_{j=a}^{j=x} \sum_{i=0}^{i=n_j} \left(T_{T_{i_j}} + T_{R_{i_j}} + T_{L_{i_j}} + T_{U_{i_j}}\right) + (TU_m)(FT_r) \quad (31)$$

$$\frac{FT_r + GT}{PT} = \text{Aircraft operating days} = \text{No. A/C} \quad (32)$$

COST METHODOLOGY

Within the life cycle of each system, various missions will be performed which can be costed as a subset of the total life-cycle cost. In this study, mission costs will be developed (based on inputs from the effectiveness analysis) and expressed as cost per operating day of system operation.

Aircraft losses are usually a linear function of the number of sorties flown. The number of sorties required in this analysis is dictated by the lift requirement and will be the same for each selected candidate subsystem. Therefore, the net aircraft loss will be a function of the threat and the aircraft vulnerability. It is anticipated that the investment cost of each modified air transport system will differ by a small amount. This small difference in cost, multiplied by normally expected small aircraft loss, will contribute little or nothing to the evaluation of the selected candidate cargo restraint systems and therefore is not considered essential to adequately construct total mission cost.

Cost Parameters Defined

I_{c_k} = Total mission investment cost for total system equipped with cargo restraint subsystem k (life cycle investment amortized for one operating day).

OC_{FH} = Operating cost per flight hour: the sum of the aircraft POL cost per flight hour and the aircraft recurring parts cost per flight hour.

OC_{GH_K} = Operating cost per ground hour divided by the loading and unloading labor cost, the ancillary ground handling equipment cost, and additional labor costs, all of which are amortized per unit of ground hour operation for each candidate subsystem k.

The total mission cost M_K for each candidate cargo restraint system for one operating day is:

$$M_K = \ldots \quad (OC_{FH}) \ (FT_r) + (OC_{GW_K}) \ (GT) \qquad (33)$$

Cost-Effectiveness Index

The cost-effectiveness index (CEI) for each candidate subsystem k is the product of effectiveness and mission cost per aircraft as follows:

$$CEI_K = (\text{No. A/C})_k \times M_K \qquad (34)$$

This CEI can then be ratioed to a base system (usually the existing system) to show the relative cost effectiveness (R_{CEI}) of each system,

$$R_{CEI} = \frac{(\text{No. A/C})_2 \ M_2}{(\text{No. A/C})_k \ M_k} \qquad (35)$$

7.3 SYSTEM EFFECTIVENESS EVALUATION

For this evaluation, a 33,000-pound gross weight helicopter was assumed, with the capability of carrying 11,400 pounds of cargo payload (including passengers) for a 20-nautical-mile mission.

When utilizing the existing Army tiedown methods for correct restraint, predicated on the 90th percentile level of survivability (see Table X), it was found that the quantity of tiedown fittings, as patterned in the CH-47 helicopter floor system, was insufficient. To correct this situation, an idealized floor tiedown pattern (see Figure 125) was conceived which increased the number of tiedown fittings to the desired quantity, with the same tiedown fitting matrix dimensions as the actual floor system. This idealized floor tiedown pattern concept was used hypothetically within the existing CH-47 helicopter shell in order to evaluate specific restraint systems on an equal basis. Other restraint systems studied could be used within the existing floor tiedown arrangement and were therefore appraised on the present pattern.

7.3.1 CARGO RESTRAINT TECHNIQUES

Cargo types selected for the specified mission are predicated on the cargo distribution pertinent to an infantry brigade movement (see Appendix VI). The cargo envelope consists of vehicles, prepalletized loads, and POL drums. The vehicle weights range from 1,090 pounds for a 1/4-ton trailer to 5,660 pounds for a 3/4-ton truck. The palletized load was assumed to weigh 1,400 pounds, and the drums were stacked in groups of four, weighing 1,436 pounds. When applying the longitudinal 11g load factor (90th percentile survivability level), it was not possible to

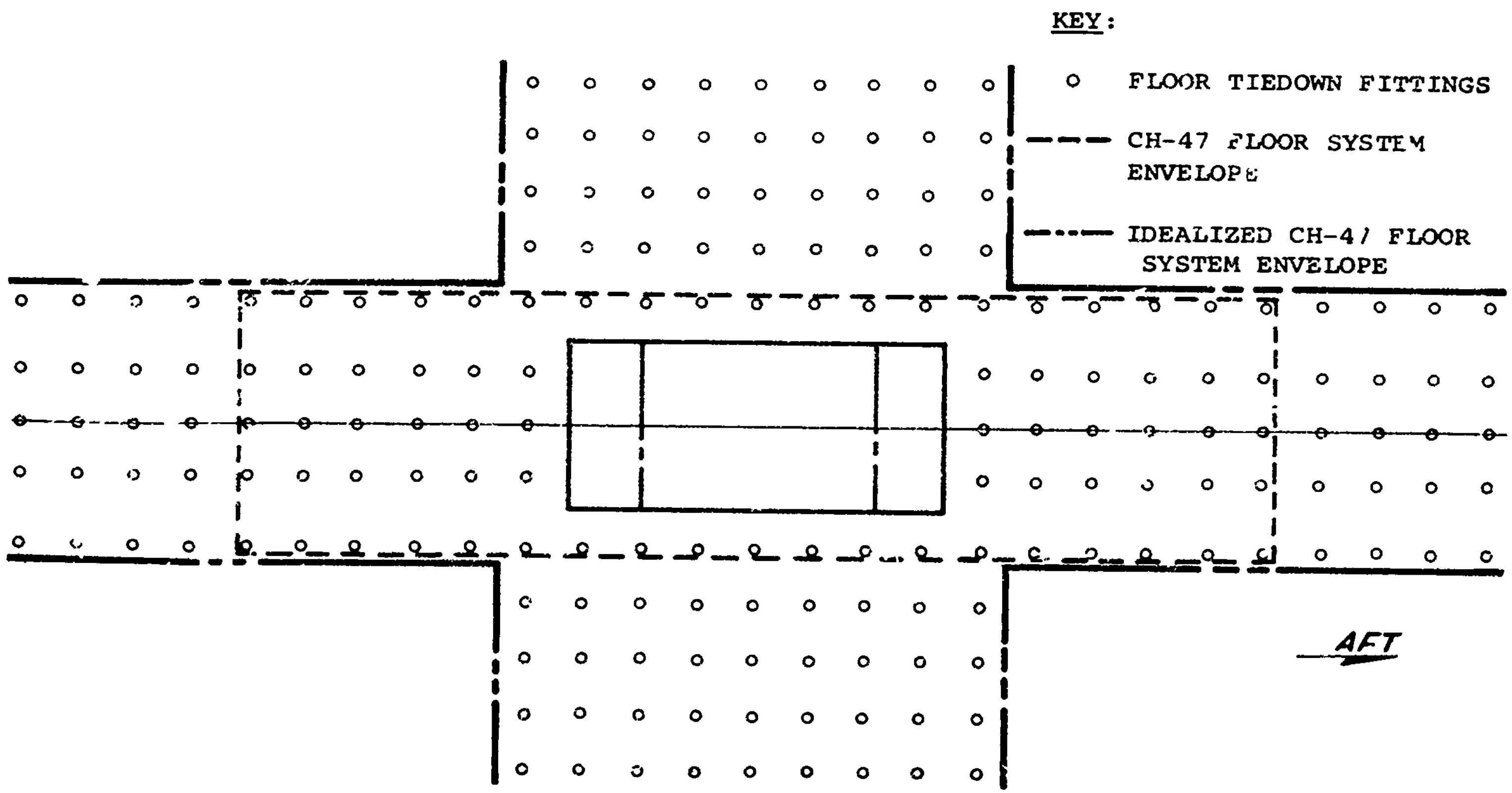


Figure 125. Idealized Floor Tiedown Pattern.

restrain the 3/4-ton truck utilizing existing Army restraint methods; consequently, it was omitted from the cargo distribution. The configurations depicted in Figures 126 through 145 delineate the methods of cargo restraint based on the use of existing Army nylon-strap methods with correct restraint, 5K load attenuators with low-elastic straps, and 7.5K load attenuators with low-elastic straps. The experimental 5K and 10K load attenuators with low-elastic straps were also considered for this evaluation.

1. Existing Army Restraint Methods with Correct Restraint

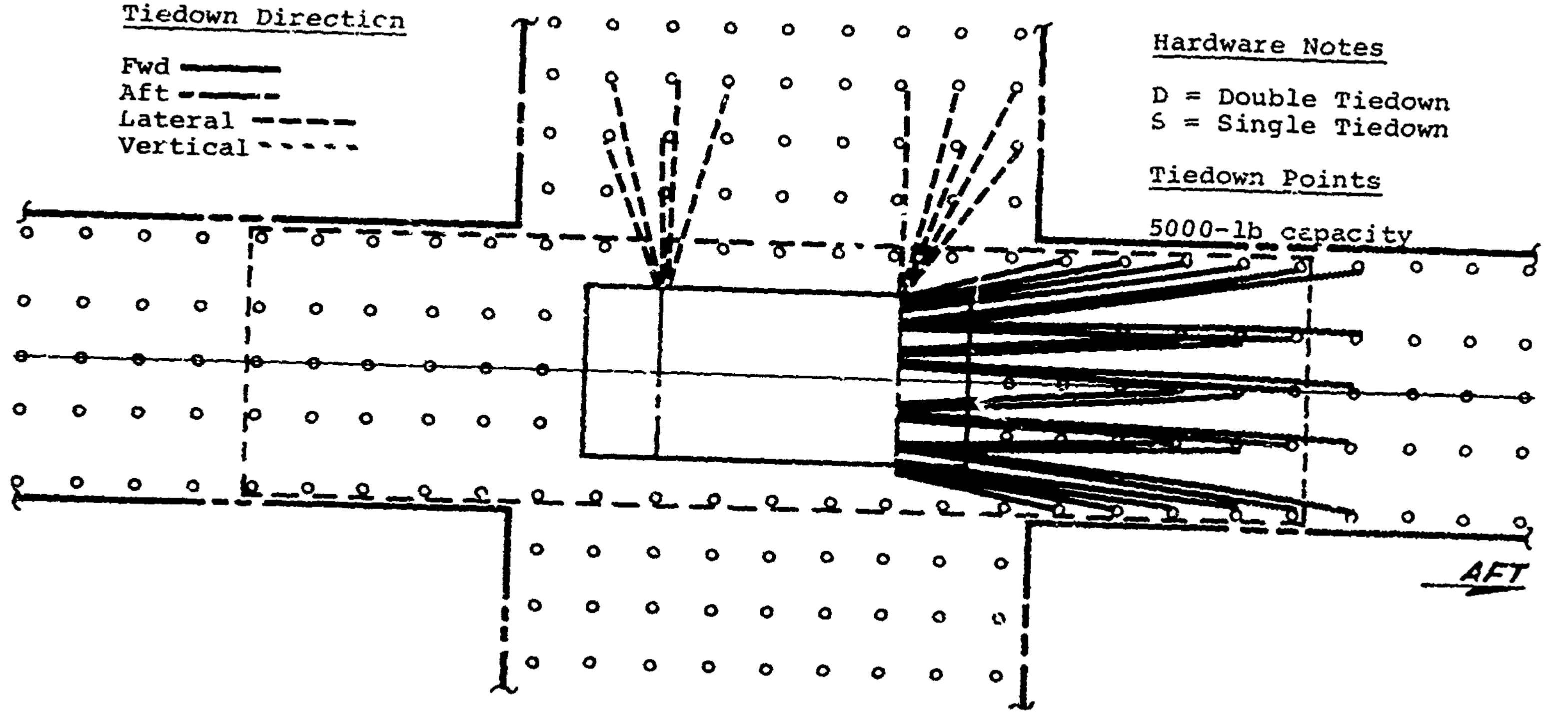
This method of restraint considers only existing Army nylon tiedown devices, as applicable. The chain devices, which are part of Army inventory, are of little use in correct restraint because of the rigid characteristics of the material. It is obvious from Figures 126 and 127 that the Army methods of correct restraint, using the CH-47 floor system, are limited to restraining cargo of relatively low weight. This is attributed to the excessive number of restraints required, based on the 90th percentile level of survivability criteria.

2. 5K and 10K Experimental Load Limiter Devices with Low-Elastic Straps

These load limiting devices are the self-stowing, wire-bending type and were developed by the All American Engineering Company for USAAVLABS. (See References 21 and 27.) This tiedown system utilizes a mixture of 5K and 10K units for a given restraint direction. The use of three straps wrapped around a component part of a 1/4-ton truck and tied to six tiedown floor fitting locations (doubling the restraint load) is required for the 5K restraint system defined in paragraph 3, following. It was found that the total number of required tiedown devices does not change by replacing two of the three straps with two 10K load limiters. Also, little time advantage was realized in rigging and derigging. The data in the systems effectiveness columns in Table XX tends to correlate this evaluation.

3. 5K Load Limiter Devices with Low-Elastic Straps

Figures 128 through 136 delineate the use of the 5K capacity load attenuators with low-elastic straps to restrain cargo to the design load factors criteria predicated on the 90th percentile level of survivability. The preferred energy absorbers are the tube-ball type.



Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap	Fwd	Aft	Lat. Ea Side	Vert
1	M151 ¼-ton Truck	Aft	2350	37		13D+ 1S		4D+ 2S	-

Figure 126. Maximum Design G Load Level Criteria Restraint of Cargo Type A-6 Using Existing Army Nylon Straps (Restraints Shown for Lateral and Longitudinal Forward Direction Only).

Tiedown Direction

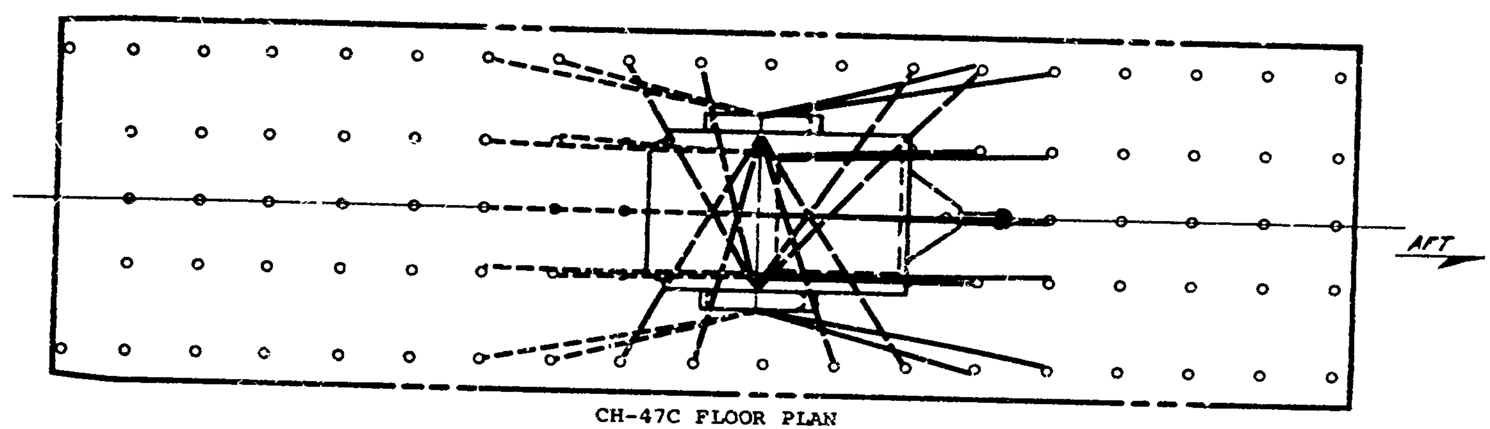
Fwd ——— Lateral – – – –
Aft -·—·- Vertical - - - - -

Tiedown Points

5000-lb capacity

Hardware Notes

D = Double Tiedown
S = Single Tiedown



CH-47C FLOOR PLAN

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap	Fwd	Aft	Lat. Ea Side	Vert
1	M101 ¼-ton Trailer	Aft	1090	28	5K	5D	5D	2D	-

Figure 127. Maximum Design G Load Level Criteria Restraint Using Existing Army Nylon Straps.

Tiedown Direction

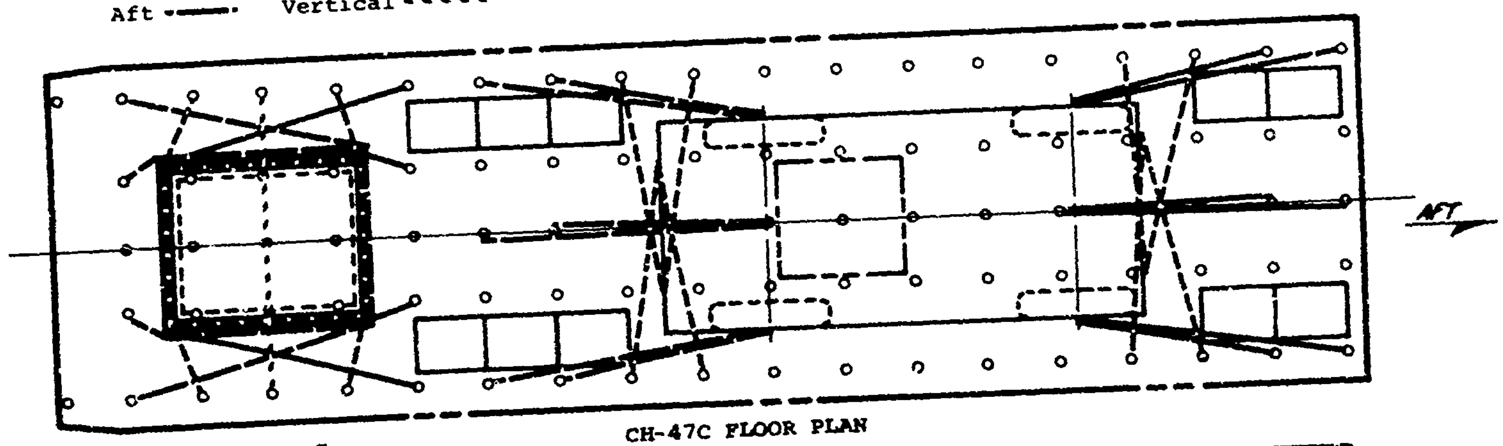
Fwd ——— Lateral — — —
Aft —·—· Vertical - - - - -

Tiedown Points

5000-lb Capacity

Hardware Notes

D = double tiedown

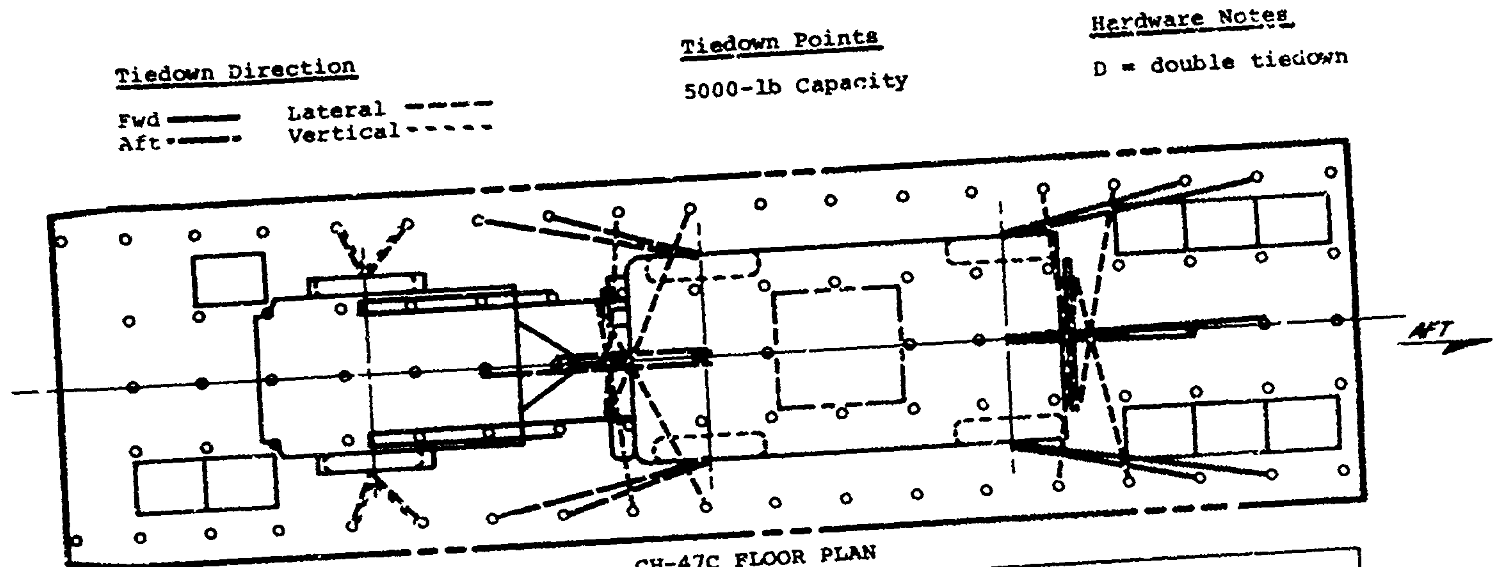


CH-47C FLOOR PLAN

System 7

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used No.	Cap.	Fwd	Aft	Lateral Ea Side	Vertical
1	M151 1/4-ton truck	Aft	2,350	20	5K	3D	3D	2D	
2	1 pallet	Aft	1,400	14	5K	2D	2D	1D	1D

Figure 128. Maximum Design G Load Level Criteria Restraint of Cargo Type A-1 Using 5K Load Limiters with Low-Elastic Straps.



System 7

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used: No.	Cap.	Fwd	Aft	Lateral Ea Side	Vertical
1	M151 1/4-ton truck	Aft	2,350	20	5K	3D	3D	2D	0
2	M100 1/4-ton trailer	Aft	1,090	12	5K	2D	2D	1D	*

*vertical restraint provided by lateral

Figure 129. Maximum Design G Load Level Criteria Restraint of Cargo Type A-2 Using 5K Load Limiters with Low-Elastic Straps.

Tiedown Direction

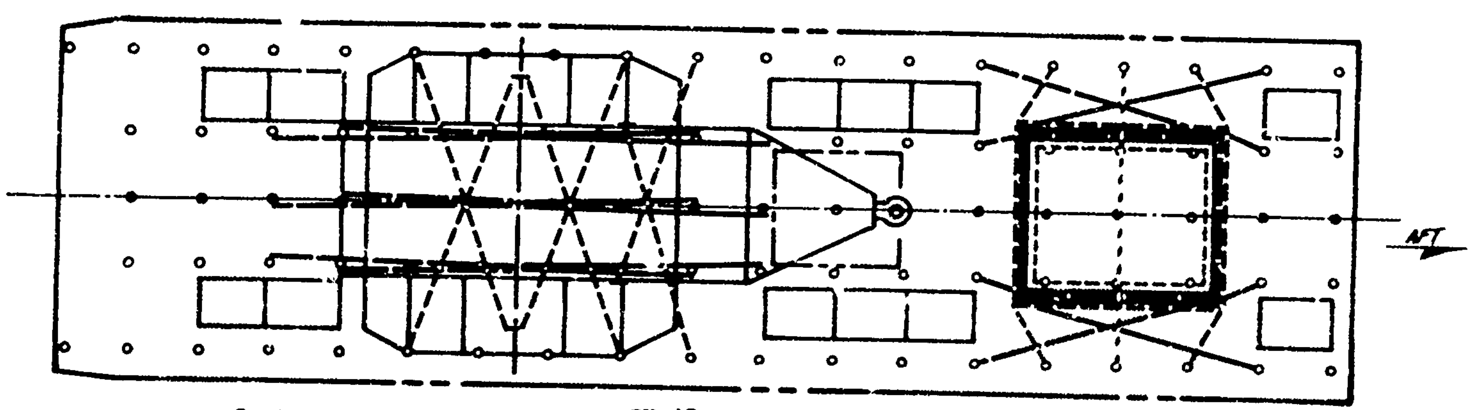
Fwd ——— Lateral — — —
Aft — - — Vertical - - - - -

Tiedown Points

5000-lb Capacity

Hardware Notes

D = double tiedown
S = single tiedown



System 7

CH-47C FLOOR PLAN

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap.	Fwd	Aft	Lateral Ea Side	Vertical
1	M107 1-1/2-ton water trailer	Aft	2,280	24	5K	3D	3D	2D +1S	
2	1 pallet	Aft	1,400	14	5K	2D	2D	1D	1D

Figure 130. Maximum Design G Load Level Criteria Restraint of Cargo Type A-3 Using 5K Load Limiters with Low-Elastic Straps.

Tiedown Direction

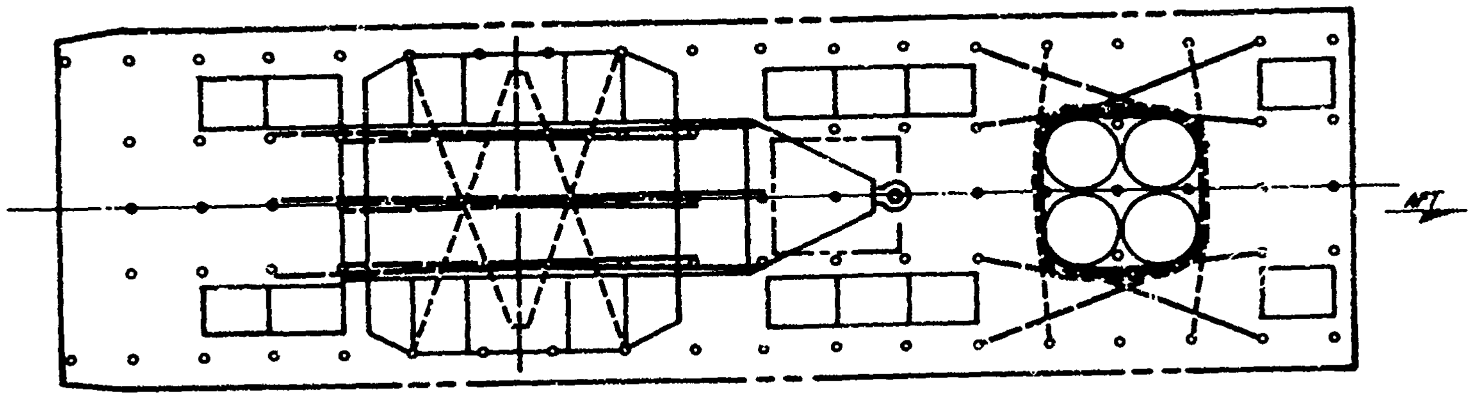
Fwd ——— Lateral — — —
Aft -—- Vertical - - - -

Tiedown Points

5000-lb Capacity

Hardware Notes

D = double tiedown



System 7

CH-47C FLOOR PLAN

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap.	Fwd	Aft	Lateral Ea Side	Vertical
1	M107 1-1/2-ton water trailer	Aft	2,280	16	5K	3D	3D	1D	
2	4 55-gallon drums	Aft	1,436	16	5K	2D	2D	1D	2D

Figure 131. Maximum Design G Load Level Criteria Restraint of Cargo Type A-4 Using 5K Load Limiters with Low-Elastic Straps.

Tiedown Direction

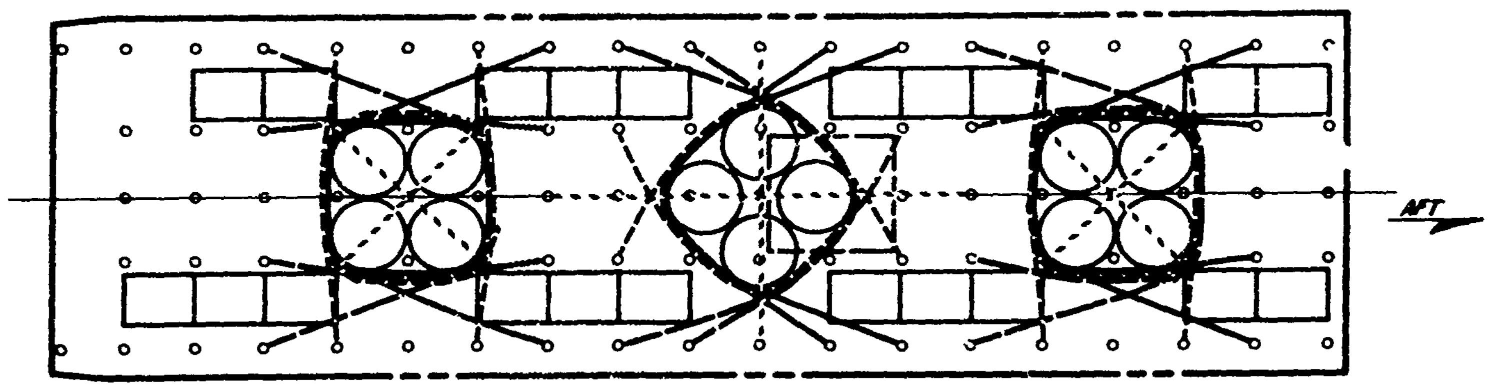
Fwd ——— Lateral – – – –
Aft •——• Vertical - - - - -

Tiedown Points

5000-lb Capacity

Hardware Notes

D = double tiedown

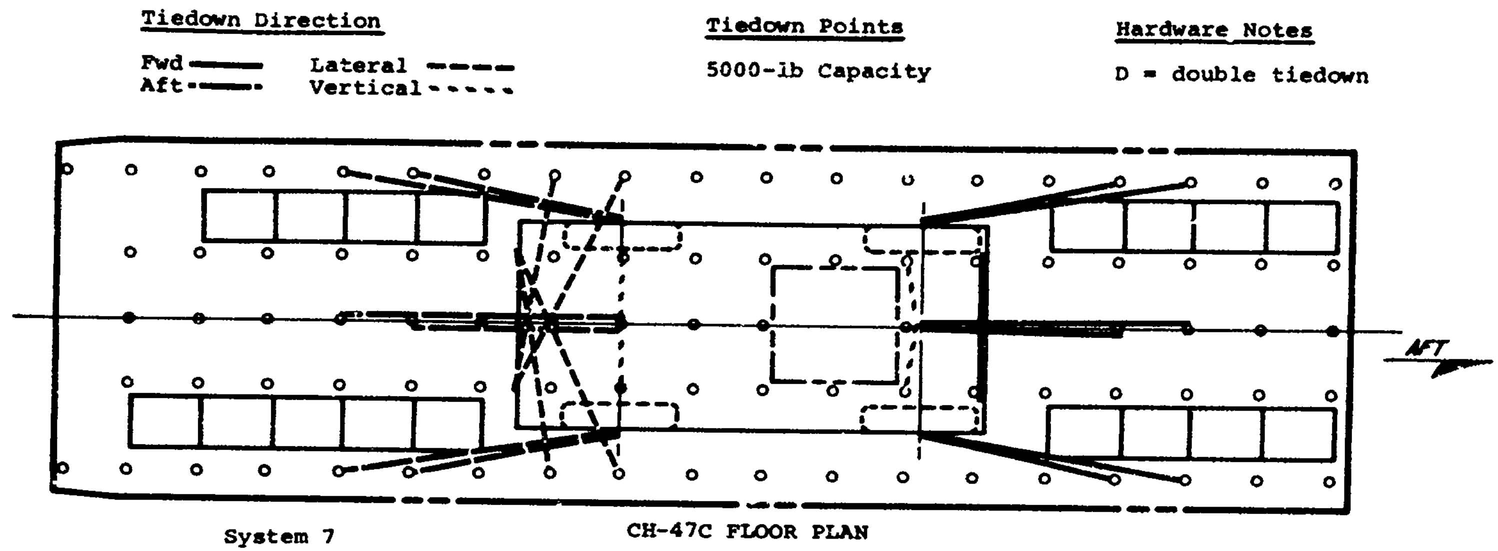


System 7

CH-47C FLOOR PLAN

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap.	Fwd	Aft	Lateral Ea Side	Vertical
1	12 55-gallon drums		4,308	48	5K	6D	6D	3D	6D

Figure 132. Maximum Design G Load Level Criteria Restraint of Cargo Type A-5 Using 5K Load Limiters with Low-Elastic Straps.



Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap.	Fwd	Aft	Lateral Ea Side	Vertical
1	M151 1/4-ton truck	Aft	2,350	24	5K	3D	3D	2D	2D

Figure 133. Maximum Design G Load Level Criteria Restraint of Cargo Type A-6 Using 5K Load Limiters with Low-Elastic Straps.

Tiedown Direction

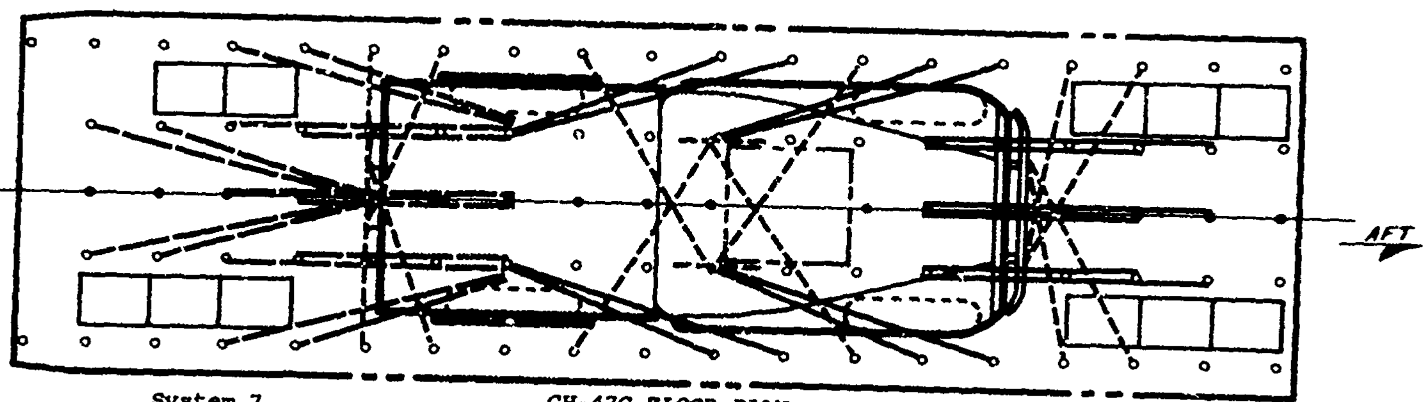
Fwd ———— Lateral – – – –
Aft –·–·–· Vertical · · · · ·

Tiedown Points

5000-lb Capacity

Hardware Notes

D = double tiedown



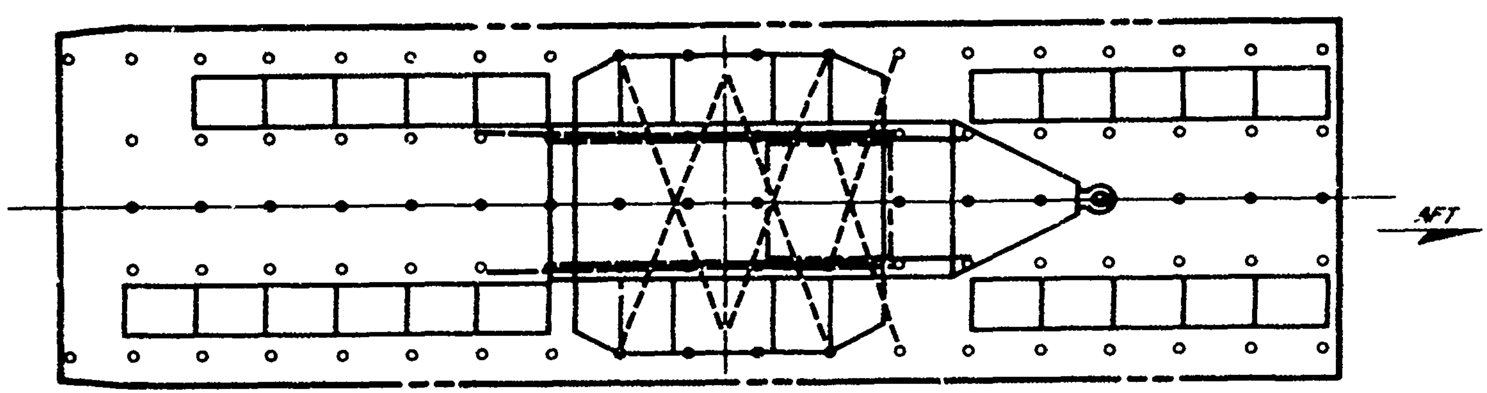
System 7

CH-47C FLOOR PLAN

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap.	Fwd	Aft	Lateral Ea Side	Vertical
1	M37 3/4-ton truck	Aft	5,660	40	5K	7D	7D	3D	

Figure 134. Maximum Design G Load Level Criteria Restraint of Cargo Type A-7 Using 5K Load Limiters with Low-Elastic Straps.

Tiedown Direction	Tiedown Points	Hardware Notes
Fwd —— Lateral – – –	5000-lb Capacity	D = double tiedown
Aft •—• Vertical - - - - -		S = single tiedown

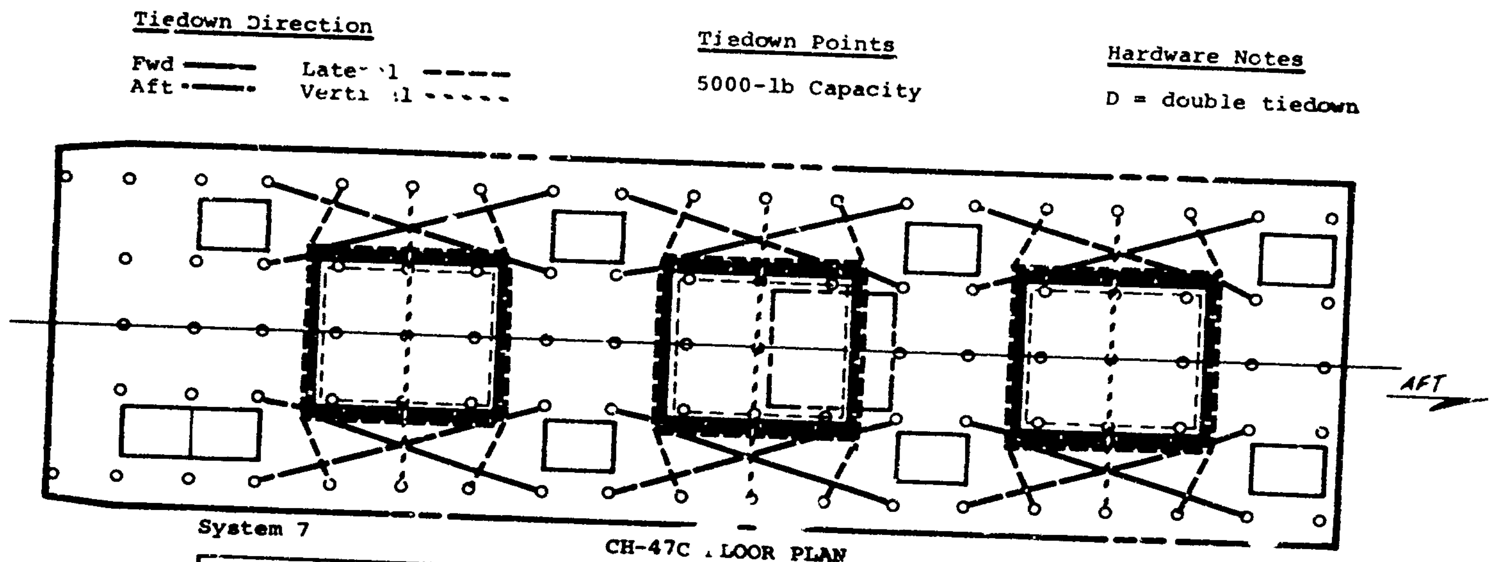


CH-47C FLOOR PLAN

System 7

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used No.	Cap.	Fwd	Aft	Lateral Ea Side	Vertical
1	M107 1-1/2-ton water trailer	Aft	2,280	14	5K	2D	2D	1D + 1S	-

Figure 135. Maximum Design G Load Level Criteria Restraint of Cargo Type A-8 Using 5K Load Limiters with Low-Elastic Straps.



Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap.	Fwd	Aft	Lateral Ea Side	Vertical
1	3 pallets	Aft	4,200	42	5K	6D	6D	3D	3D

Figure 136. Maximum Design G Load Level Criteria Restraint of Cargo Type A-9 Using 5K Load Limiters with Low-Elastic Straps.

TABLE XX. COMPARISON OF SYSTEMS CARGO HANDLING OPERATIONS (CH-47 FLOOR TIEDOWN PATTERNS)

Restraint System	No. of Sorties	No. of Aircraft Required	Total Cargo Handling Time (min)*
1	**	**	**
2	181	42	7797
7	181	29	7813
7a	181	27	6787

* From tables in Appendix VI.

** Not computed, since relatively few cargo types can be restrained with existing CH-47 floor tiedown pattern.

4. <u>7.5K Load Limiter Devices with Low-Elastic Straps</u>

This restraint system is similar in concept to the 5K restraint system described in paragraph 2. The major difference is the capability of the 7.5K unit to sustain a 50 percent higher load intensity. Figures 137 through 145 delineate the use of the 7.5K capacity load attenuator devices with low-elastic straps to restrain cargo to the design load factors criteria predicated on the 90th percentile level of survivability. The tube-ball type is preferred for the 7.5K load devices.

7.3.2 COMPARISON OF SYSTEMS EFFECTIVENESS

The systems effectiveness study demonstrates the use of standard and new restraint system concepts in a typical mission. Factors evaluated in the study are cargo handling operations, restraint system component weights, restraint systems cost-estimating procedure, and systems cost for a mission profile; these factors are unified into a relative cost-effectiveness index.

1. <u>Cargo Handling Operations</u>

Cargo handling operations are evaluated from the standpoint of the total time it takes to load, restrain, release, and unload cargo (see Appendix VI). The cargo types and the floor configurations used are given in

Tiedown Direction

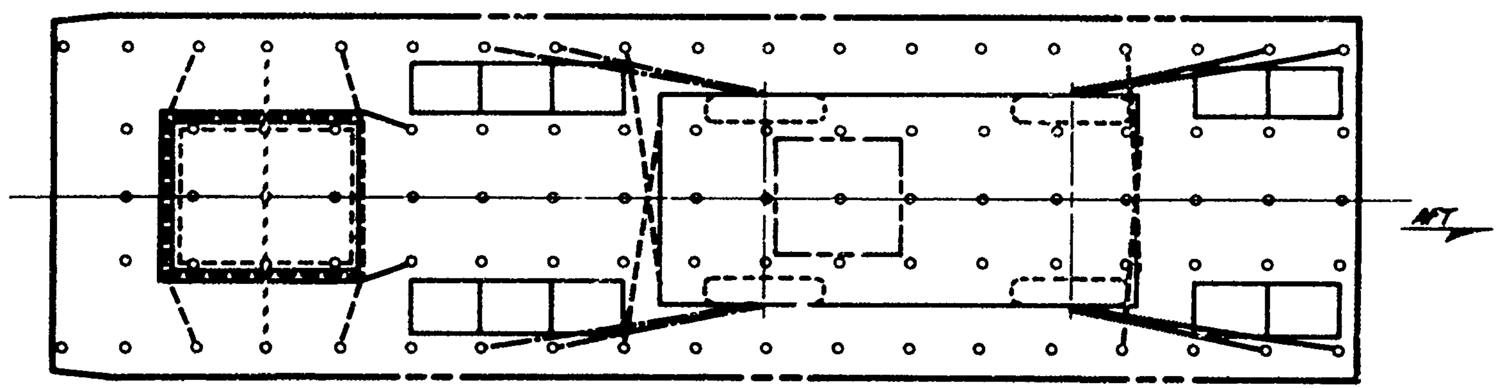
Fwd ——— Lateral – – – –
Aft ·——· Vertical - - - - -

Tiedown Points

7500-lb Capacity

Hardware Notes

D = double tiedown
S = single tiedown



CH-47C FLOOR PLAN

System 7

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap	Fwd	Aft	Lateral Ea Side	Vertical
1	1 pallet	Aft	1,400	10	7.5K	1D	1D	1D	1D
2	M151 1/4-ton truck	Aft	2,350	8	7.5K	2D	2D	2S	

Figure 137. Maximum Design G Load Level Criteria Restraint of Cargo Type A-1 Using 7.5K Load Limiters with Low-Elastic Straps.

Tiedown Direction

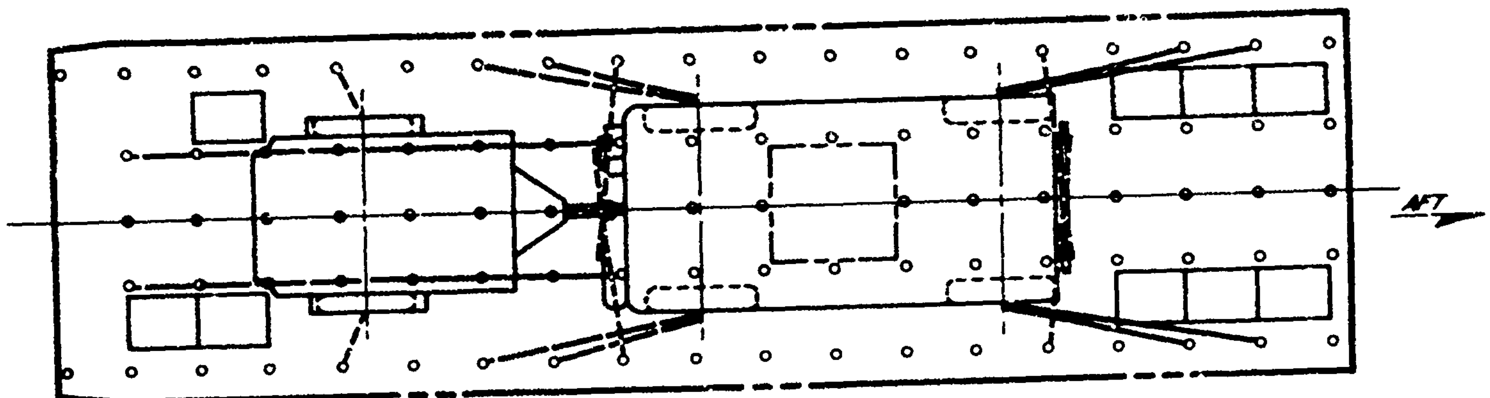
Fwd ——— Lateral – – –
Aft ·——· Vertical - - - -

Tiedown Points

7500-lb Capacity

Hardware Notes

D = double tiedown
S = single tiedown



CH-47C FLOOR PLAN

System 7a

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used No.	Cap	Fwd	Aft	Lateral Ea Side	Vertical
1	M151 1/4-ton truck	Aft	2,350	12	7.5K	2D	2D	2S	
2	M100 1/4-ton trailer	Aft	1,090	6	7.5K	2D	2D	1S	

Figure 138. Maximum Design G Load Level Criteria Restraint of Cargo Type 7-2 Using 7.5K Load Limiters with Low-Elastic Straps.

Tiedown Direction

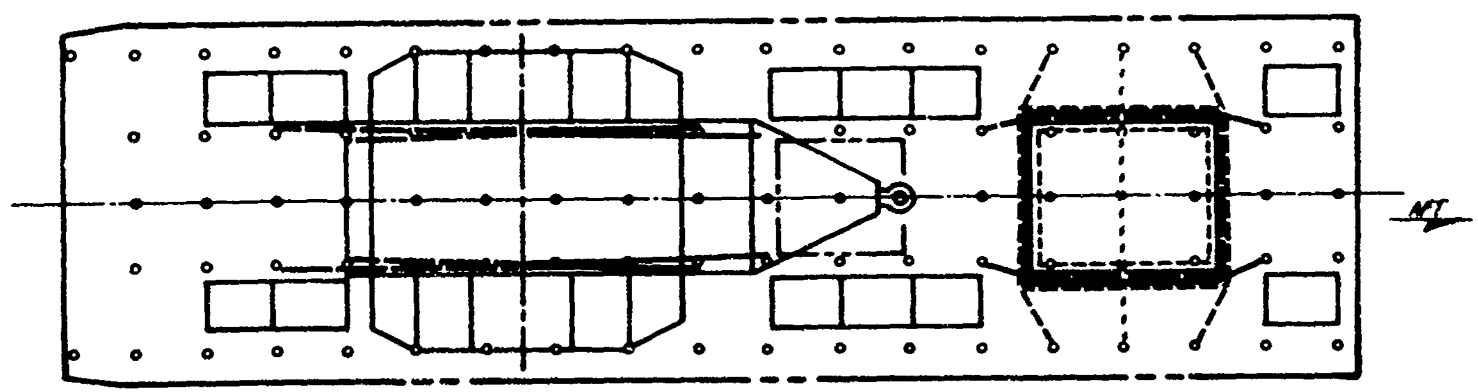
Fwd —— Lateral - - - -
Aft •—— Vertical • • • • •

Tiedown Points

7500-lb Capacity

Hardware Notes

D = double tiedown



CH-47C FLOOR PLAN

System 7a

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used No.	Cap	Fwd	Aft	Lateral Ea Side	Vertical
1	M107 1-1/2-ton water trailer	Aft	2,280	12	7.5K	2D	2D	1D	
2	1 pallet	Aft	1,400	10	7.5K	1D	1D	1D	1D

Figure 139. Maximum Design G Load Level Criteria Restraint of Cargo Type A-3 Using 7.5K Load Limiters with Low-Elastic Straps.

Tiedown Direction

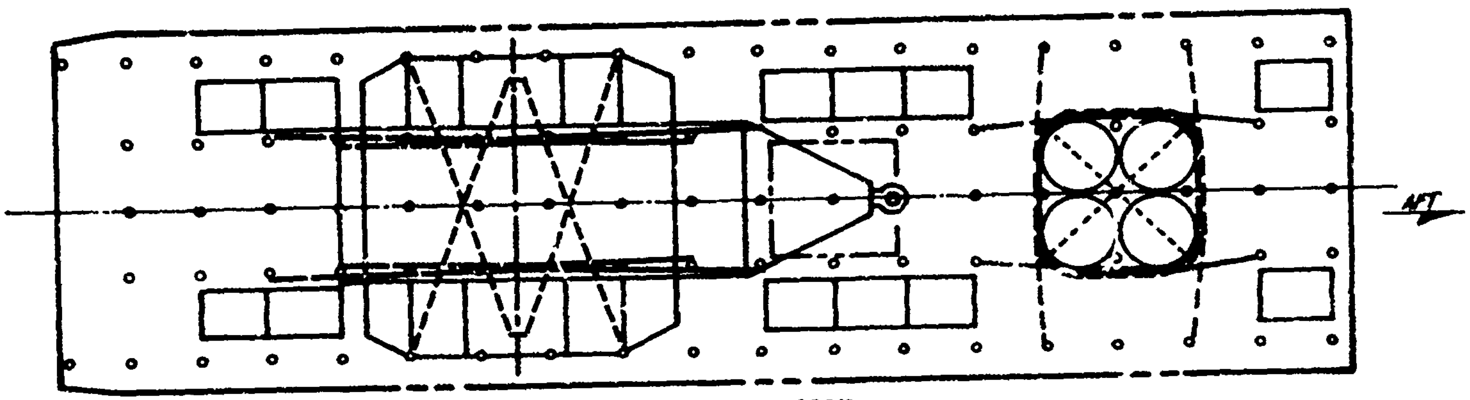
Fwd ——— Lateral — — —
Aft —·—· Vertical - - - - -

Tiedown Points

7500-lb Capacity

Hardware Notes

D = double tiedown



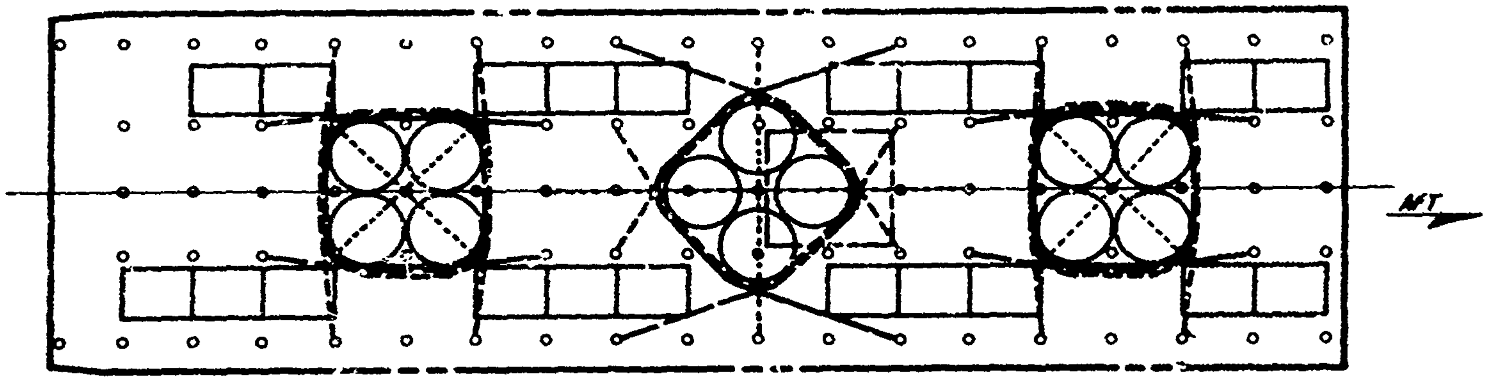
CH-47C FLOOR PLAN

System 7a

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used No.	Cap	Fwd	Aft	Lateral Ea Side	Vertical
1	M107 1-1/2-ton water trailer	Aft	2,280	12	7.5K	2D	2D	1D	
2	4 55-gallon POL drums	Aft	1,436	12	7.5K	1D	1D	1D	2D

Figure 140. Maximum Design G Load Level Criteria Restraint of Cargo Type A-4 Using 7.5K Load Limiters with Low-Elastic Straps.

Tiedown Direction		Tiedown Points	Hardware Notes
Fwd ———	Lateral — — —	7500-lb Capacity	D = double tiedown
Aft — — —	Vertical ·······		

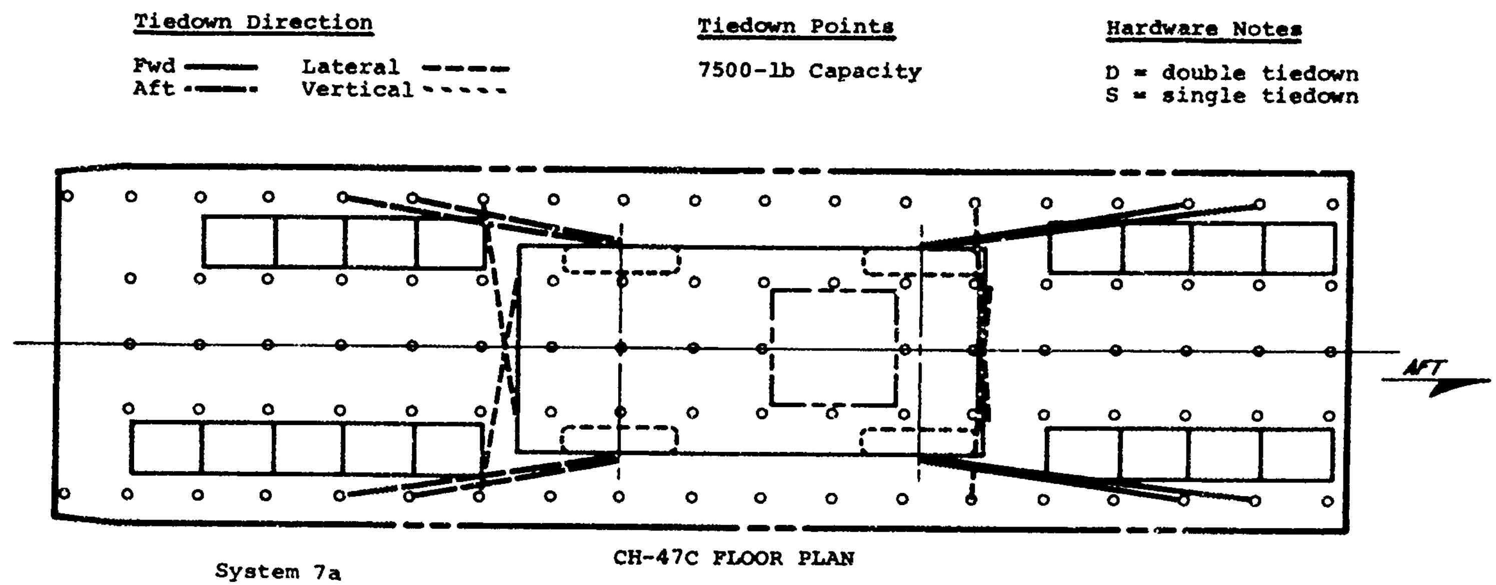


CH-47C FLOOR PLAN

System 7a

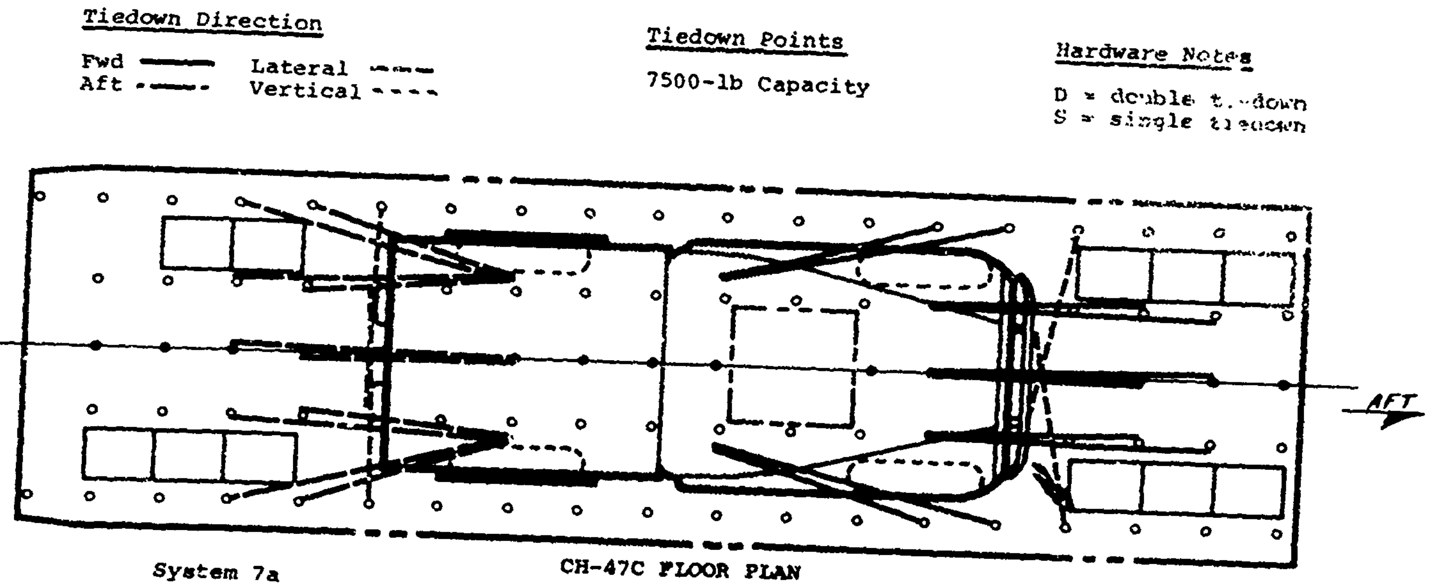
Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used: No.	Cap	Fwd	Aft	Lateral Ea Side	Vertical
1	12 55-gallon drums	Aft	4,308	30	7.5K	3D	3D	3D	2D

Figure 141. Maximum Design G Load Level Criteria Restraint of Cargo Type A-5 Using 7.5K Load Limiters with Low-Elastic Straps.



Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap	Fwd	Aft	Lateral Ea Side	Vertical
1	M151 1/4-ton truck	Aft	2,350	12	7.5K	2D	2D	2S	

Figure 142. Maximum Design G Load Level Criteria Restraint of Cargo Type A-6 Using 7.5K Load Limiters with Low-Elastic Straps.



Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap	Fwd	Aft	Lateral Fa Side	Vertical
1	M37 3/4-ton truck	Aft	5,660	24	7.5K	5D	5D	2S	

Figure 143. Maximum Design G Load Level Criteria Restraint of Cargo Type A-7 Using 7.5K Load Limiters with Low-Elastic Straps.

Tiedown Direction

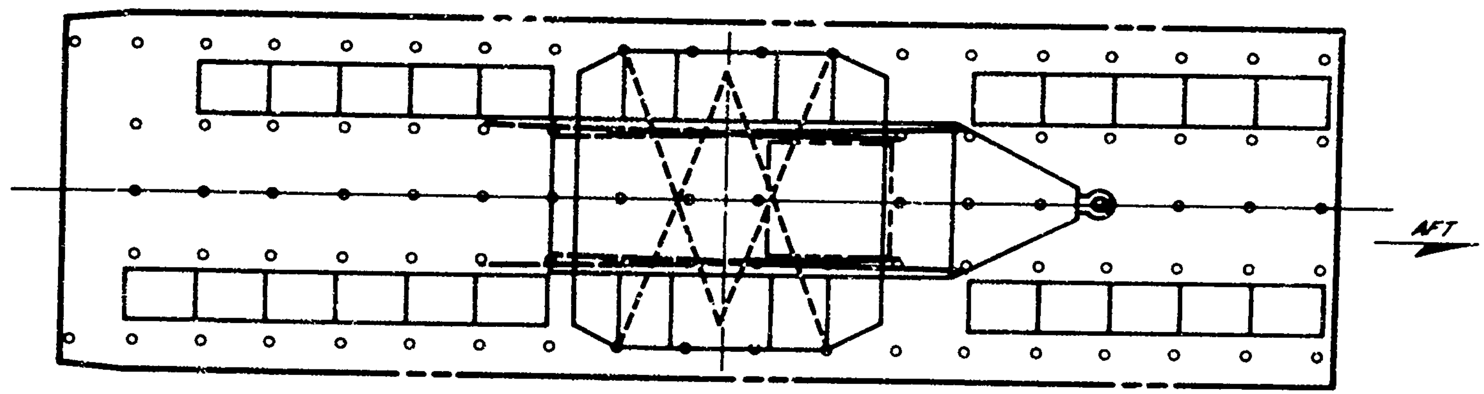
Fwd ——— Lateral —·—·—
Aft -·-·-· Vertical - - - - -

Tiedown Points

7500-lb Capacity

Hardware Notes

D = double tiedown
S = single tiedown



System 7a

CH-47C FLOOR PLAN

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap	Fwd	Aft	Lateral Ea Side	Vertical
1	M107 1-1/2-ton water trailer	Aft	2,280	12	7.5K	2D	2D	1D	

Figure 144. Maximum Design G Load Level Criteria Restraint of Cargo Type A-8 Using 7.5K Load Limiters with Low-Elastic Straps.

Tiedown Direction

Fwd ——— Aft -——-

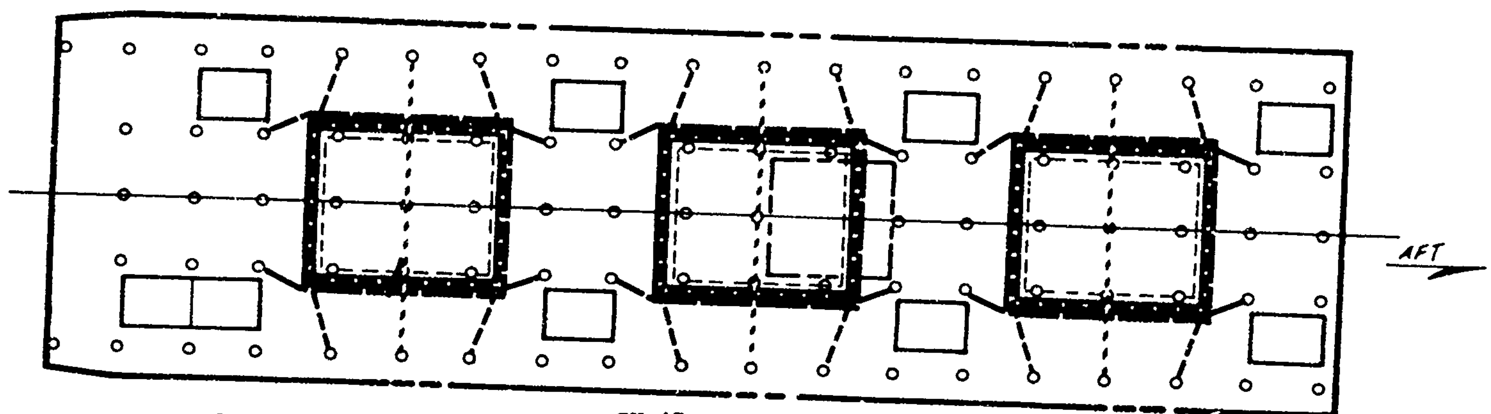
Lateral - - - - Vertical . . . . .

Tiedown Points

7500-lb Capacity

Hardware Notes

D = double tiedown



System 7a

CH-47C FLOOR PLAN

Item	Description	Facing	Weight Approx (lb)	Floor Tiedowns Used					
				No.	Cap	Fwd	Aft	Lateral Ea Side	Vertical
1	3 pallets	Aft	4,200	30	7.5K	3D	3D	3D	3D

Figure 145. Maximum Design G Load Level Criteria Restraint of Cargo Type A-9 Using 7.5K Load Limiters with Low-Elastic Straps.

TABLE XXI. CARGO TYPES CONSIDERED

Symbol	Cargo Type With CH-47 Floor Tiedown Pattern	Symbol	Cargo Type With Idealized Floor Pattern*
A-1	1 M151 1/4-ton truck 1 40-in. x 48-in. pallet 10 troops @ 240 lb ea 2 gunners @ 240 lb ea	B-1	2 M151 1/4-ton trucks 1 M100 1/4-ton trailer
A-2	1 M151 1/4-ton truck 1 M100 1/4-ton trailer 8 troops @ 240 lb ea 2 gunners @ 240 lb ea	B-2	1 M151 1/4-ton truck 1 M100 1/4-ton trailer 1 M107 1-1/2-ton water trailer 1 40-in. x 48-in. pallet
A-3	1 M107 1-1/2-ton water trailer 1 40-in. x 48-in. pallet 12 troops @ 240 lb ea 2 gunners @ 240 lb ea	B-3	1 M151 1/4-ton truck 1 M100 1/4-ton trailer 2 40-in. x 48-in. pallets
A-4	1 M107 1-1/2-ton water trailer 4 55-gallon drums @ 359 lb ea 12 troops @ 240 lb ea 2 gunners @ 240 lb ea	B-4	1 M151 1/4-ton truck 1 M100 1/4-ton trailer 8 55-gallon drums @ 359 lb ea
A-5	12 55-gallon drums @ 350 lb ea 20 troops @ 240 lb ea 2 gunners @ 240 lb ea	B-5	1 M151 1/4-ton truck 1 M100 1/4-ton trailer 1 40-in. x 48-in. pallet 4 55-gallon drums @ 359 lb ea
		B-6	12 55-gallon drums @ 359 lb ea

* For existing Army nylon strap methods (Tables XXIX and XXX), use types A-1 through A-5.

Table XXI; the required number of restraints per cargo at the maximum design g levels criteria is depicted in Table XXII; the corresponding cargo handling time rates per tiedown strap are given in Table XIX.

A comparison of restraint systems cargo handling times is shown in Tables XX and XXIII, with the number of sorties and aircraft required to complete the mission. The number of sorties is defined by the mission profile; however, the required number of sorties per restraint system depends on the usable internal cargo volume per aircraft. For example, if four vehicles are considered for a mission and two vehicles can be restrained within a given aircraft, then two sorties per restraint system are required. The total number of required aircraft is calculated by the methodology developed in Section 7.2.

Since the tube-ball device as an alternate to the AAE experimental wire-bending device (Figure 117) performs the same function, the system effectiveness was evaluated for the wire-bending unit only.

2. Restraint Systems Weight

The actual and estimated individual component weights of each restraint system considered are listed in Table XXIV. When these values are multiplied with the required component quantities (Table XXII), the total component weights are obtained; finally, the summation of these component weight values results in the pertinent restraint system weight (Table XXV).

3. Restraint Systems Cost-Estimating Procedure

The synthesized costs of the candidate cargo restraint systems are those costs pertinent to research, development, test and evaluation (RDTE), and fabrication. The RDTE costs represent the design and test effort, and test material of sufficient scope to define a production retrofit product.

The fabricated investment costs, which include the costs of material, manufacturing effort, and purchased parts, are estimated for tiedown straps with ratchet assemblies, energy absorbing devices, and airframe structural component changes or additions as required. These costs are related in the system effectiveness evaluation as depicted in Figure 124.

Specific costs of the cargo handling system (e.g., equipment available for the movement of cargo in and out of the aircraft) were not included in the cost analysis since

TABLE XXII. REQUIRED NUMBER OF CARGO RESTRAINTS AT THE 90TH PERCENTILE LEVEL OF SURVIVABILITY (VERTICAL RESTRAINTS INCLUDED)

	Category I System 1	Category I System 2			Category II System 7		Category II System 7a	
	Existing Army Methods With Nylon Straps (Note 1)	Experimental 5K and 10K Load Limiters (Note 2)			5K Load Limiter System (Notes 2 and 3)		7.5K Load Limiter System (Notes 3 and 4)	
			Load Limiter		No. of		No. of	
Cargo Type	No. of Straps	No. of Straps	Qty.	Cap.	Straps	L.L.	Straps	L.L.
1/4-ton M151 truck	46	10	4 12	10K 5K	10	20	8	12
1/4-ton M151 truck and	46	10	4 12	10K 5K	10	20	8	12
1/4-ton M100 trailer	15	6	2 8	10K 5K	6	12	4	8
3/4-ton M37 truck and	Not Feasible	20	6 28	10K 5K	20	40	14	28
M107 water trailer	44	10	4 10	10K 5K	10	18	6	12
3 pallets @ 1460 lb each	81	18	3 30	10K 5K	21	42	15	30
12 55-gal. drums	78	21	3 36	10K 5K	24	48	18	36
1/4-ton truck and	46	10	4 12	10K 5K	10	20	8	12
1 pallet	27	7	14	5K	7	14	5	10
M107 water trailer and	44	10	4 10	10K 5K	10	18	6	12
1 pallet	27	7	14	5K	7	14	5	10
M107 water trailer and	44	10	4 10	10K 5K	10	18	6	12
4 55-gal. drums	26	7	14	5K	8	16	6	12
Total straps	81 Nylon	21 Dacron			24 Dacron		18 Dacron	
Total load limiters		6-10K 36-5K			48-5K		36-7.5K	

Notes:
(1) MB-1 chains eliminated
(2) The number of energy absorbing devices used varies per system, depending on the need to use the strap in a single or double application
<u>Example</u> (for M151 Truck, Category I, System 2): 10 straps were used. Four (4) single straps attach to the four 10K load limiters, and six (6) double straps attach to the twelve 5K load limiters. The double straps have a load limiter at each end.
(3) Identical tiedown arrangement for System 2a.
(4) Identical tiedown arrangement for System 2b.

General: Tiedown requirements shown are for individual items. They are combined into aircraft loads in the systems effectiveness study. See restraint diagrams.

TABLE XXIII. COMPARISON OF SYSTEM CARGO HANDLING OPERATIONS FOR IDEALIZED FLOOR TIEDOWN PATTERN

Restraint System	No. of Sorties	No. of Aircraft Required	Total Cargo Handling Time (min)*
1	181	42	17,434
2	107	22	7,797
7	107	22	7,813
7a	107	20	6,787

* See tables in Appendix VI.

TABLE XXIV. COMPONENT SYSTEM WEIGHTS

Item	Description	Weight Per Item (lb)
1	CH-47 5K tiedown fitting (inst)	0.42
2	CH-47 10K tiedown fitting (inst)	1.7
3	CGU-1/B tiedown strap (GFE) assembly	3.64
4	Type I load attenuator (AAE) device (5K)	4
5	Type II load attenuator (AAE) device (10K)	5.5
6	Tube-ball load limiter device as integral unit (5K)	1.1 (est)
7	Tube-ball load limiter device as add-on alternative (5K)	1.43 (est)
8	Tube-ball load limiter device as integral unit (7.5K)	1.40 (est)
9	Tube-ball load limiter device as add-on alternative (7.5K)	1.90 (est)
10	Nylon straps (MC-1)	3.51
11	Dacron straps	8.0

TABLE XXV. RESTRAINT SYSTEM WEIGHTS

Component Parts \ Restraint System	Category I (Weight in Pounds)				Category II (Weight in Pounds)			
	No. 1 CH-47 Nylon Restraints	No. 2 Exp. 5K & 10K LL	Alternate		No. 7 Integral 5K LL	No. 7A Integral 7.5K LL	Alternate (See Figure 117)	
			No. 2A 5K LL	No. 2b 7.5K LL			5K LL	7.5K LL
Structural Adaptations	-	-	-	26	2	5	2	28
MB-1 Chains	-	-	-	-	-	-	-	-
MC-1 or CGU-1, and Nylon Strap	284	-	-	-	-	-	-	-
Straps (Dacron)	-	168	195	144	195	144	195	144
5K Load Limiters (Wire)	-	144	-	-	-	-	-	-
10K Load Limiters (Wire)	-	33	-	-	-	-	-	-
5K Load Limiter (Tube/Ball)	-	-	68	-	52	-	68	-
7.5K Load Limiter (Tube/Ball)	-	-	-	53	-	57	-	53
4 Nets (69 pounds each)	-	-	-	-	-	-	-	-
Aeroquip Quick-Release Bridle (8.5 pounds)	-	-	-	-	-	-	-	-
Existing Tiedown	-	-	-	*	*	*	-	-
Total System Weight (Est)	284	345	263	223	249	206	265	225

* 50-lb weight trade-off potential from existing tiedown system (see Figure 96)

these were considered to be common items, available for use with all cargo restraint systems.

Other considerations pertinent to the synthesized cost estimates are:

a. Vendor estimates were used on purchased parts.

b. RDTE costs were prorated over 127 operational CH-47C aircraft and were considered equally applicable to the CH-47A and B models.

c. Cost estimates of engineering labor and manufacturing labor include tooling, material, overhead, G&A and earnings.

d. Normal in-house estimating practices and pricing rates were used.

4. Systems and Mission Costs

The mission costs are defined to include RDTE, initial investment, and operations and maintenance (O&M). The RDTE and initial investment costs attributable to an operational aircraft for one day were determined by amortizing the total cost over all operational aircraft for a 10-year period. The operations and maintenance costs contain both the direct operating cost and ground support personnel cost. Operations and maintenance costs were reduced to a flight-hour basis and were charged to the mission through the number of hours flown.

The CH-47C total systems cost was used for the baseline aircraft. Cost changes to RDTE and flyaway for the four systems were estimated through an industrial engineering approach which analyzed the drawings and parts involved. Estimated manhours were converted to 1969 dollars by using current labor, overhead, and profit rates. Although changes to O&M cost items were minimal, small adjustments were made to both initial and replenishment spares. The components involved in the restraint system were considered to be integral (passive rather than functional) parts of structure. Spares adjustments were based on the latest removal rates on the CH-47C structures (4000 hour MTBR). All other cost items in the total system cost analysis were unchanged. Maintenance manhours per flight hour were considered unaffected by the restraint system; thus, direct manpower costs remained unchanged.

The ground support personnel used for loading, securing, and unloading were held constant for the effectiveness study. The costs of these men have been included and are

the same for each restraint system studied. The cost of a cargo handling system (rollers, etc.) was included in and considered part of the aircraft cost. (The same cargo handling equipment was to be used for each of the various restraint systems considered.)

The costs of RDTE and initial investment were prorated over the number of CH-47C operational aircraft (127) on a per-day basis. Operations and maintenance costs were applied per flight hour under the assumption that each aircraft flies 600 hours per year for 10 years.

Development costs were estimated for Systems 7 and 7a, which were selected for quantitative examination. This cost was prepared as described above, and is given in Table XXVI. Basic differences in cost represent an estimate of the engineering cost impact of structural changes to uprate the restraint system. Development costs for the energy absorber were considered low relative to structural change costs and are already sunk (expended) in System 2, experimental load limiters. Likewise, no development cost was used for the basic CH-47 system now in use.

Purchase prices for these restraint systems are compared in Table XXVII. The comparators, Systems 1 and 2, incur additional investment to establish a restraint comparison at the 90th percentile level of survivability. The unit price for Systems 2b and 7a is associated with uprating the energy absorber and the aircraft structure; whereas, for System 7 uprating only the aircraft structure is required. This is attributable to the extensive development of the 5K tube-ball load limiter by AAE.

Costs shown for Systems 2a and 2b (Tables XXVI, XXVII, and XXVIII) would also apply to the alternate tube-ball use illustrated in Figure 117.

Table XXVIII shows the life-cycle cost impact of the four restraint systems. The relative difference is of minor significance. Each design in the quantitative evaluation represents a negligible change in the complexity of the total aircraft as a system. Restraint subsystems that would have involved a more significant cost change and complexity were eliminated from the analysis by a qualitative preselection, in terms of simplicity and overall design objectives.

Operating costs from Table XXVIII were used as impacts to the trade-off model.

TABLE XXVI. RESTRAINT SYSTEM DEVELOPMENT COST INCREMENT						
	Restraint System					
Item	1	2	2a**	2b	7	7a
Total Engineering Labor and Material Costs (in dollars)	Sunk	Sunk	-	59,300	59,000	77,650
Unit Cost per Aircraft (in dollars)*	-	-		480	475	610

*Costs prorated over 127 operational, CH-47C aircraft for consistency in using CH-47 performance data; unit costs would be lower if applied to entire CH-47 fleet which could include the CH-47A, B, and C aircraft.

**The development cost increment was not relevant for comparative purposes inasmuch as the 5K tube-ball load limiter was developed by AAE.

TABLE XXVII. RESTRAINT SYSTEM PURCHASE PRICE INCREMENT						
	Restraint System					
Item	1	2	2a**	2b	7	7a
Total Manufacturing Labor and Material per Aircraft (in dollars)	-	-	-	21,100	23,300	25,000
Total Purchased Parts per Aircraft (in dollars)	495	3,465	2,365	2,110	1,875	1,685
Unit Purchase Price per Aircraft (in dollars)*	495	3,465	2,365	23,210	25,175	26,685

*Costs of retrofit installation; production incorporation would be lower.

**The manufacturing cost increment was not relevant for comparative purposes inasmuch as the 5K tube-ball load limiter was developed by AAE.

TABLE XXVIII. TEN-YEAR SYSTEMS COST PER OPERATIONAL AIRCRAFT (IN MILLIONS OF DOLLARS)[1]

Item	Restraint System 1	2	7[5]	7a[5]
RDTE	Sunk	Sunk	0.001	0.001
Initial Investment				
Peculiar to restraint system	0	0.004	0.037	0.039
Remaining investment[2]	2.634	2.634	2.634	2.634
Operations and Maintenance				
Peculiar to restraint system[3]	0	0.001	0.004	0.004
Remaining O&M [4]	3.505	3.505	3.505	3.505
Grand total, 10-year system cost	6.139	6.144	6.180	6.182
Aircraft cost per day (in dollars)	722	723	731	731
O&M cost per flight hour (in dollars)	584	584	585	585

NOTES:

(1) The model used to generate the 10-year system costs described above is entitled PLACE, Parametric Life Cycle Army Cost Estimator, and is fully described in Boeing Document D8-2243-1 (Parametric Life Cycle Army Cost Estimator). Essentially, it is patterned after the A.R.C.S.A. II report (Aviation Requirements for the Combat Structure of the Army, 1967 Planning Research, Classified) and factors.

(2) Includes: Maintenance float, attrition, initial fuel stocks, aircraft related GSE, and nonaircraft supplies.

(3) System components considered expendable part of structure (@ 4000 hp MTBR).

(4) Includes: direct and maintenance and flight personnel pay allowance, fuel, replacement parts and depot overhaul, indirect maintenance, replacement training and travel, support personnel, medical and Army wide costs.

(5) Costs for Systems 2a and 2b are not significantly different from 7 and 7a, respectively.

5. Relative Cost-Effectiveness Index

The data of Tables XXIX and XXX are presented to evaluate the effectiveness of the selected candidate restraint systems. The values in the column for relative cost-effectiveness index are a product of the number of aircraft and total cost to complete the defined mission (depicted in Tables XXXI and XXXII). A sample calculation determining these values can be found in Appendix VI. The other columns in Tables XXIX and XXX, with the exception of aircraft performance, are already defined in this section.

6. Aircraft Performance Effectiveness

Aircraft performance data was established to evaluate the internal cargo payloads effectiveness for the various restraint systems. This was accomplished by a mathematical expression: the sum of the product of each cargo type weight multiplied by its corresponding number of sorties, divided by the product of the total mission sorties times the available payload. These values were put on a relative basis by dividing the values for the existing Army restraint method into the value for the alternate restraint methods. A sample calculation is given in Table XXXVI.

7.3.3 RESULTS OF ANALYSIS

The critical shortcomings of existing Army restraint methods as compared to the alternate systems restraint methods (when restraining to the maximum design g load factors) are as follows:

1. Large quantity of tiedown devices required to restrain typical cargo (Table XXII).
2. Because of the large quantity of tiedown devices required, the elasticity characteristics of variant length tiedown devices completely eliminate the 3/4-ton truck from the cargo mission.
3. Total mission cargo handling time is 224 percent higher (Table XXIII) when compared with an idealized tiedown floor pattern.
4. Necessity of an additional 74 sorties to complete mission (Table XXIII).
5. Required number of aircraft to complete mission is 90 percent higher when compared to a common aircraft tiedown floor pattern (Table XXXII).
6. Mission costs can be 80 percent higher (Table XXXII).

TABLE XXIX. COMPARISON OF CH-47 CARGO RESTRAINT SYSTEMS EFFECTIVENESS FOR 90TH PERCENTILE LEVEL OF SURVIVABILITY (CH-47 FLOOR TIEDOWN PATTERN)

				Design Complexity					Systems Effectiveness	
System No.	Description (See Table XXI for Cargo Types)	Sys Wt (lb)	Total Cargo Operation Time (Min)	RDTE ($/A/C)	O&M ($/Flt Hr)	Purchase Price ($/A/C)	Total Mission Cost ($)	A/C Performance (Internal Payload Effectiveness*)	No. A/C Reqd	Relative Cost-Effectiveness Index
1**	Existing Army nylon straps	284	17,434	-	[illegible]34	495	62,038	1.00	42	1.00
2	Add-on experimental 5 & 10K LL	345	7,797	-	584	3,465	52,600	1.00	42	1.68
7+	Integral 5K LL	249	7,813	475	585	25,175***	52,957	1.00	29	1.67
7a+	Integral 7.5K LL	206	6,787	610	585	26,685	51,500	1.00	27	1.85
Table Reference		XXV	XX	XXVI	XXVIII	XXVII	XXXI		XXXI	XXXI

* No difference realized since same number of sorties were used for evaluation on a common basis.

** Used A-1 through A-5 cargo types with idealized floor tiedown pattern.

*** Purchase price is for energy absorbers installed under CH-47 floor.

\+ In comparison to Systems 7 and 7a, the effectiveness parameters for Systems 2a and 2b, respectively, would not be significantly different. Differences in weight and purchase price are shown in Tables XXV, XXVI, XXVII, and XXVIII.

TABLE XXX. COMPARISON OF CH-47 CARGO RESTRAINT SYSTEMS EFFECTIVENESS FOR 90TH PERCENTILE LEVEL OF SURVIVABILITY (IDEALIZED FLOOR TIEDOWN PATTERN)

System No.	Description (See Table XXI for Cargo Types)	Sys Wt (lb)	Total Cargo Operation Time (Min)	Design Complexity RDTE ($/A/C)	Design Complexity O&M ($/Flt Hr)	Purchase Price ($/A/C)	Total Mission Cost ($)	A/C Performance (Internal Payload Effectiveness*)	Systems Effectiveness No. A/C Reqd	Systems Effectiveness Relative Cost-Effectiveness Index
1*	Existing Army nylon straps	284	17,434	-	584	495	62,038	1.00	42	1.00
2	Add-on experimental 5 & 10K LL	345	7,797	-	584	3,465	34,672	1.69	22	3.36
7+	Integral 5K LL	249	7,813	475	585	25,175**	34,859	1.69	22	3.34
7a+	Integral 7.5K LL	206	6,787	610	585	26,685	33,398	1.69	20	3.84
Table Reference		XXV	XX	XXV	XXVIII	XXVII	XXXII		XXXII	XXXII

* Used A-1 through A-5 cargo types with idealized floor tiedown pattern.

** Purchase price is for energy absorbers installed under CH-47 floor.

\+ In comparison to Systems 7 and 7a, the effectiveness parameters for Systems 2a and 2b, respectively, would not be significantly different. Differences in weight and purchase price are shown in Tables XXV, XXVI, XXVII and XXVIII.

TABLE XXXI. COMPARISON OF SYSTEMS COST-EFFECTIVENESS INDEX (CH-47 FLOOR TIEDOWN PATTERN)

Restraint System	1 No. of Aircraft Required	2 Total Mission Cost ($)	Cost-Effectiveness Index (CEI) 10^{-5} (1 x 2)	Relative Cost-Effectiveness Index (RCEI) (Ratio of System 1 to Alternate System)
1*	42	62,038	25.65	1.00
2	29	52,600	15.23	1.68
7**	29	52,957	15.36	1.67
7a**	27	51,500	13,90	1.85

* Used Idealized Floor Tiedown Pattern.

**In comparison to Systems 7 and 7a, the effectiveness parameters for Systems 2a and 2b, respectively, would not be significantly different. Differences in weight and purchase price are shown in Tables XXV, XXVI, XXVII, and XXVIII.

TABLE XXXII. COMPARISON OF SYSTEMS COST-EFFECTIVENESS INDEX (IDEALIZED FLOOR TIEDOWN PATTERN)

Restraint System	1 No. of Aircraft Required	2 Total Mission Cost ($)	Cost-Effectiveness Index (CEI) 10^{-5} (1 x 2)	Relative Cost-Effectiveness Index (RCEI) (Ratio of System 1 to Alternate System)
1	42	62,038	25.65	1.00
2	22	34,672	7.63	3.36
7	22	34,859	7.67	3.34
7a	20	33,398	6.68	3.84

TABLE XXXIII. PERCENTILE OF SURVIVABILITY FOR GIVEN CARGO AND RESTRAINT SYSTEMS (BASED ON DYNAMIC CRITERIA) USING TECHNICAL MANUAL TIEDOWN PROCEDURE

Cargo Type (See Appendix III.)	Total No. of Tiedown Devices Used	Cargo Weight (lb)	Percentile of Crash Survivability for Dynamic Criteria									
			Existing Nylon Straps as Restraint System (Replacing Chains with Nylon Straps of 5K Capacity)				Low-Elastic Restraint Devices with 5K Load Attenuators*			Low-Elastic Restraint Devices with 7.5K Load Attenuators*		
			Restraint Direction				Restraint Direction			Restraint Direction		
			Fwd	Aft	Lat.	Vert.	Fwd	Aft	Lat.	Fwd	Aft	Lat.
M100 1/4-ton trailer	4	1090	37.5	39	58.3	OK	76	77.5	90	87	87.5	90
M107 water trailer	4	2260	24.5	16	32	U	63	56	76	75	73	84
M151 1/4-ton truck	8	2350	25	42	41	OK	69	81	80	81	90	87.5
M170 1/4-ton ambulance	9	2963	35	35.5	39.5	U	71.5	72.5	80	83	84	87
M37 3/4-ton truck	14	5660	30	21	43.5	U	67	60	86	79	72.5	90

U - Under strength based on 5.0 static g criterion for nylon straps.
OK - Restrained to at least 5.0 g rebound load criterion for nylon straps.
* - M107 water trailer vertical rebound restraint is under strength (static restraint is 1.7g versus allowable 3.75g for load attenuator system).

7. Most of the cargo for a typical mission cannot be fully restrained in a CH-47 helicopter.

It is evident from the conclusions presented in the above paragraph that the system of load attenuation devices with low-elastic straps offers unique advantages, from the standpoint of fully restraining cargo in a CH-47 helicopter to both the dynamic g load factors criteria (90th percentile level of survivability) and the static g load factor criterion for vertical rebound. From the standpoint of relative cost effectiveness, the dynamic load limiter restraint systems are as much as 382 percent more effective (e.g., the 7.5K restraint system in Table XXXII) than the existing Army nylon restraint system. Furthermore, System 7a is significantly higher in effectiveness when considering that the existing Army tiedown method is not conducive to restraining cargo predicated on the maximum design criteria load intensities. From the systems effectiveness data presented, it appears that virtually no difference exists between the experimental 5K and 10K load limiter restraint system (System 2) and the 5K load limiter restraint system (System 7).

The purchase price (Table XXIX), which includes a retrofit installation, is relatively higher for the latter system. This higher dollar value is attributed to placing the 5K load limiters under the aircraft floor. If utilized as add-on units to the tiedown devices, little difference exists (see Tables XXVI and XXVII).

The 7.5K load limiter restraint system appears to offer more advantages for the following reasons:

1. Requires the minimum number of tiedown devices at the maximum restraint design levels for the systems studied.

2. During combat operations, relatively few cargo tiedown devices can be employed; the use of 7.5K units will result in the highest restraint survivability percentile levels under these conditions.

3. Relatively lowest mission cost (Tables XXIX and XXX).

4. Requires fewer aircraft to complete mission (Table XXXII).

5. Most effective system retrofittable to the CH-47 helicopter (Tables XX and XXIII).

From the values listed in the Purchase Price column of Table XXX, the proposed 7.5K restraint system appears to be the most expensive system. This is attributed to the incurred cost of retrofitting the unit to the existing CH-47 helicopter airframe

locations below the floor level. This cost includes installation and local airframe structural beef-up. If incorporated into the production line, a further decrease in the purchase price will be realized.

Higher capacity load limiters are desirable. The load attenuation value is dependent on the capability of the cargo to react the maximum restraint loads that can result from a survivable crash condition. However, higher load attenuation levels above the 7.5K value will definitely require extensive changes to the CH-47 airframe structure. Therefore, higher restraint systems were not studied. From this section and Section 7.4, RESTRAINT TECHNIQUES VERSUS CRASH SURVIVABILITY, it is obvious that the maximum feasible constant load level device can and should be incorporated as an integral part of the structure for present and future aircraft.

7.4 RESTRAINT TECHNIQUES VERSUS CRASH SURVIVABILITY

The pertinent parameters that are associated with percentile of crash survivability are cargo weights, cargo tiedown restraints, and cargo g load. The curves in Figures 146 through 151 and in Appendix III show the development of these parameters.

These curves were primarily delineated for existing Army restraint methods using nylon straps, low-elastic restraint devices with 5K load attenuators, and low-elastic restraint devices with 7.5K load attenuators to determine the percentile of survivability that can be accomplished for a dynamic restraint system predicated on existing Army techniques of restraining cargo. The use of an existing Army nylon tiedown device with a load attenuator was not considered because of the high deformation characteristic of the webbing device. An elastic strap-load attenuator combination is discussed in the DESIGN CRITERIA section of this report.

The curves shown on Figures 146 through 149 show that about twice the percentile of survivability can be realized (at a given g level) when considering a load attenuation restraint system instead of the existing nylon web-type restraint system. For example, the 11.0 and 5.0 longitudinal and lateral restraint g values are associated with the 90th percentile level for the load limiting system; whereas, for the existing nylon strap system, these g values and the 48.5 are associated with the 48.5 and 58.0 percentile levels for the longitudinal and lateral direction, respectively. For the 90th percentile level, the existing nylon restraint methods require 36 and 17.5 g restraint factors for the longitudinal and lateral direction, respectively. Therefore, in addition to increased survivability, tremendous gains in the reduction of total tiedown devices and time to rig and derig cargo are realized when using the load attenuation system. This is readily apparent when a large number of

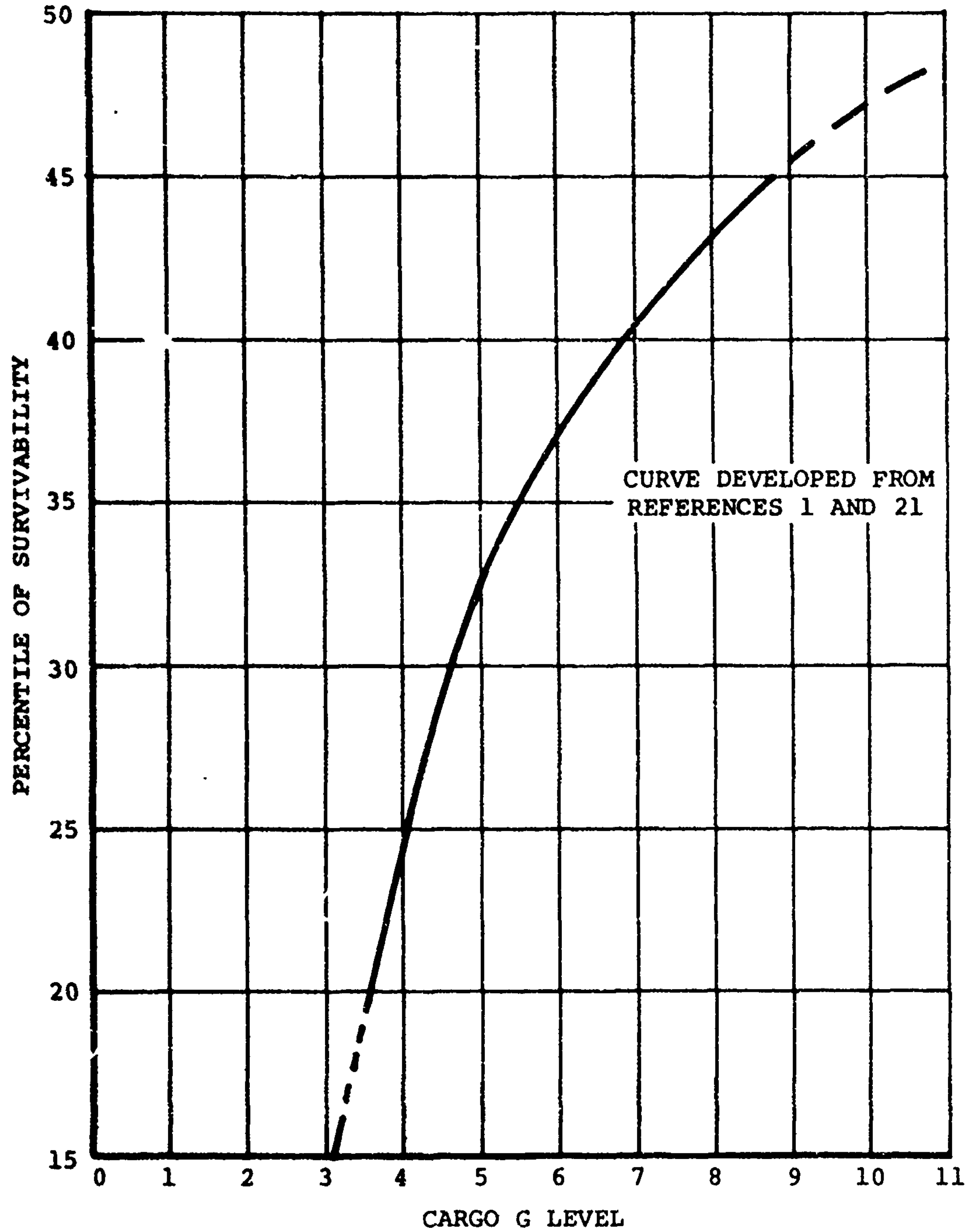


Figure 146. Percentile of Survivability Versus Cargo G Level for Existing Nylon Straps in the Longitudinal Impact Direction.

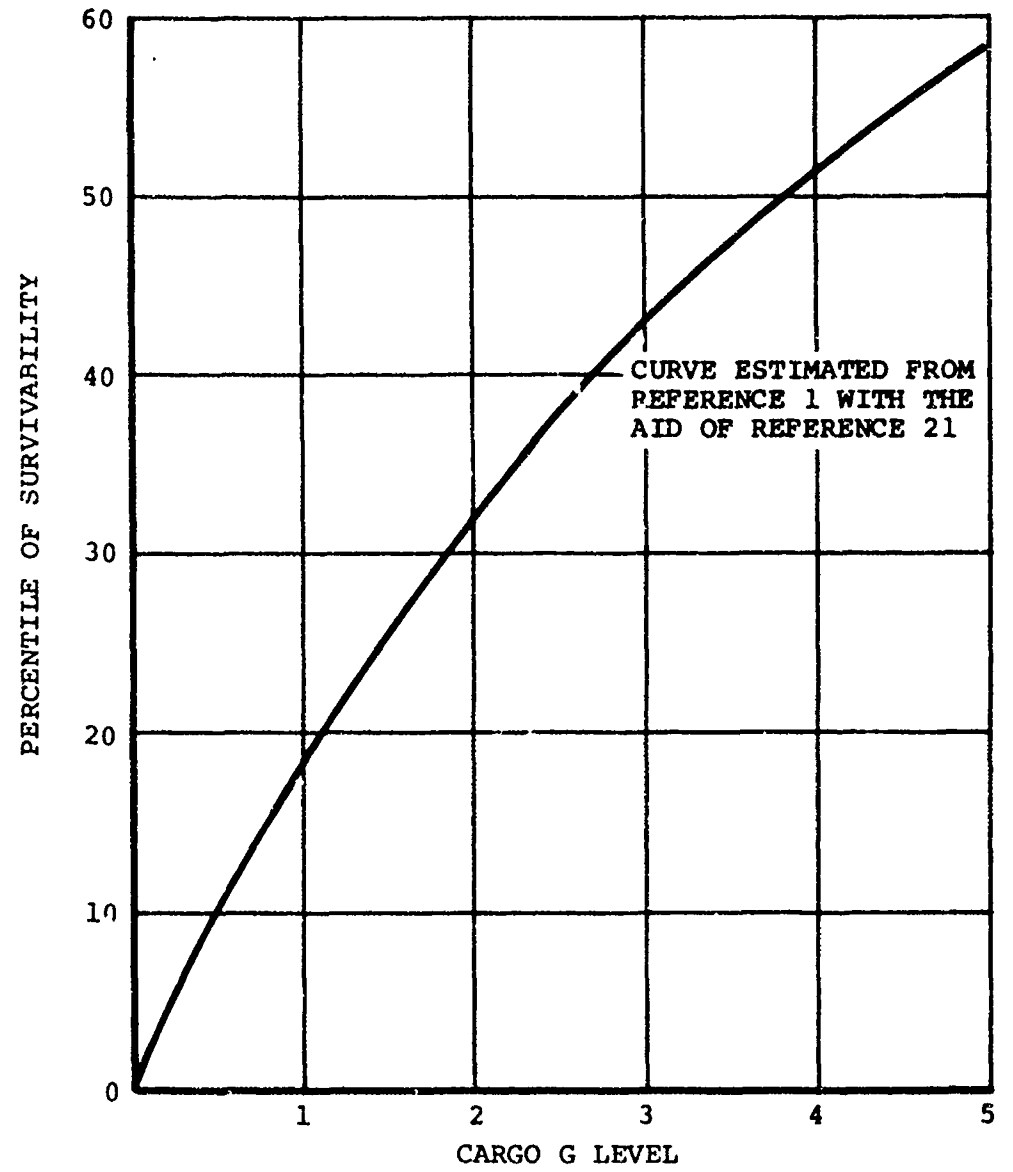


Figure 147. Percentile of Survivability Versus Cargo G Level for Existing Nylon Straps in the Lateral Impact Direction.

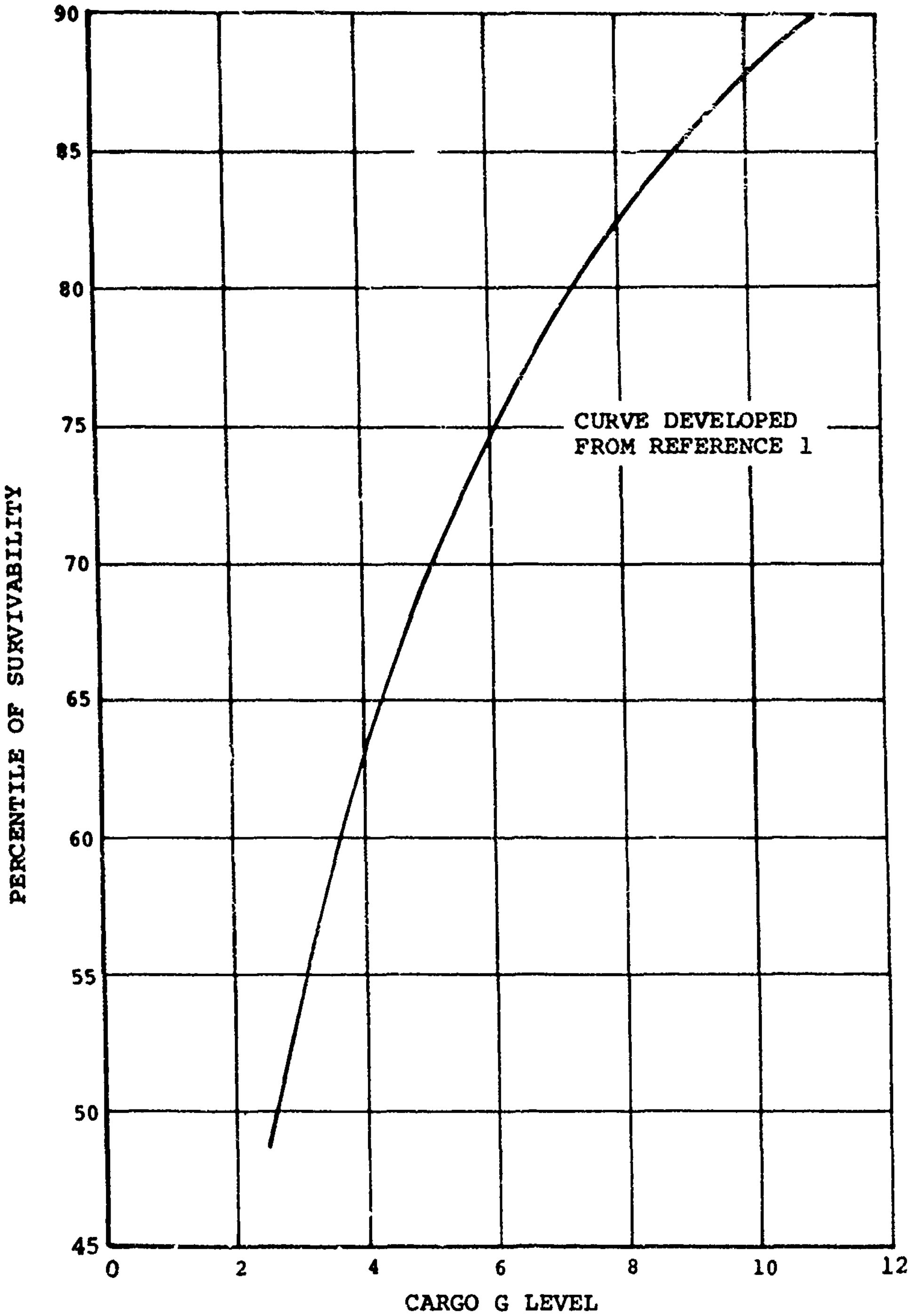


Figure 148. Percentile of Survivability Versus Cargo G Level for Constant Load Attenuation with 8-Inch Stroke in the Longitudinal Impact Direction.

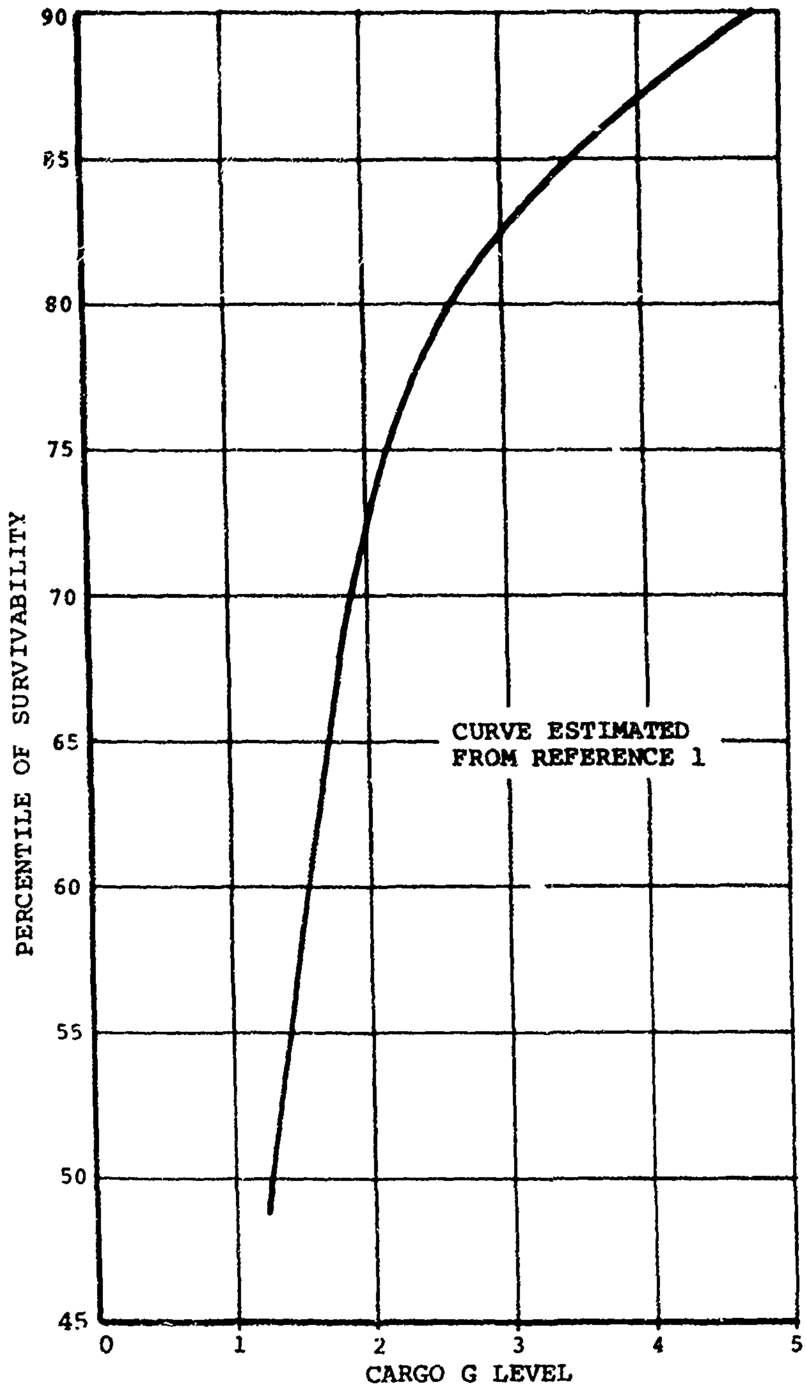


Figure 149. Percentile of Survivability Versus Cargo G Level for Constant Load Attenuation with 8-Inch Stroke in the Lateral Impact Direction.

restraint devices are required for a given impact direction. With the existing methods correctly restrained, the floor tiedown pattern utilization results in variant length tiedown devices, resulting in a degradation of the restraint system. The addition of more devices is then required in order to allow the system to react to the anticipated load level. The load limiting system tends toward the minimum number of restraint devices.

The curve of Figure 150 was delineated to show the relative cargo weights that can be restrained for the given tiedown systems at a defined percentile level. At the 90th percentile level, for the longitudinal impact direction, the 5K load limiting system is capable of restraining 327 percent higher cargo weights than the existing nylon strap method; the 7.5 system, 491 percent; and the 10K system, 653 percent. In terms of total restraint cargo weights at the design survivability levels, the 5K and higher load limiting systems require relatively few tiedown devices when compared to the existing Army system.

In general, the existing nylon method requires a relatively large number of straps based solely on a basic design g load factor calculation for a given weight,

$$\text{No. of Straps} = \frac{\text{(design g load factor) x weight}}{\text{restraint capacity}} \quad (36)$$

As pointed out in the preceding paragraph, an additional number of straps is necessary to accommodate the floor tiedown patterns that exist in aircraft. For the same weight, a load limiting system requires relatively few restraints, and the need for additional restraints is infrequent. For example, at the 90th percentile level, a 1/4-ton vehicle weighing 2,350 pounds requires a total of 17 tiedown devices for the forward restraint direction, utilizing the existing nylon strap method, and a total of 25,850 (2350 x 11) divided by 15,000 (7500 x 2), or 2 tiedown devices, for the 7.5K load attenuator system. Of the 17 devices, 13 are doubled around a vehicle component for twice the capacity (tied to 26 floor fittings); 1 is used as a single device; and 3 are added to lengthen three devices. (When doubled around a vehicle component to give twice the capacity, each end of a strap is tied to a floor fitting.)

The basic calculation for the existing system indicates that 84,600 (2350 x 36) divided by 10,000 (5000 x 2), or 7 tiedown devices are required instead of the 17 devices indicated above. The additional restraints are required to eliminate the degradation resulting from the variant length devices, when utilizing standard tiedown locations.

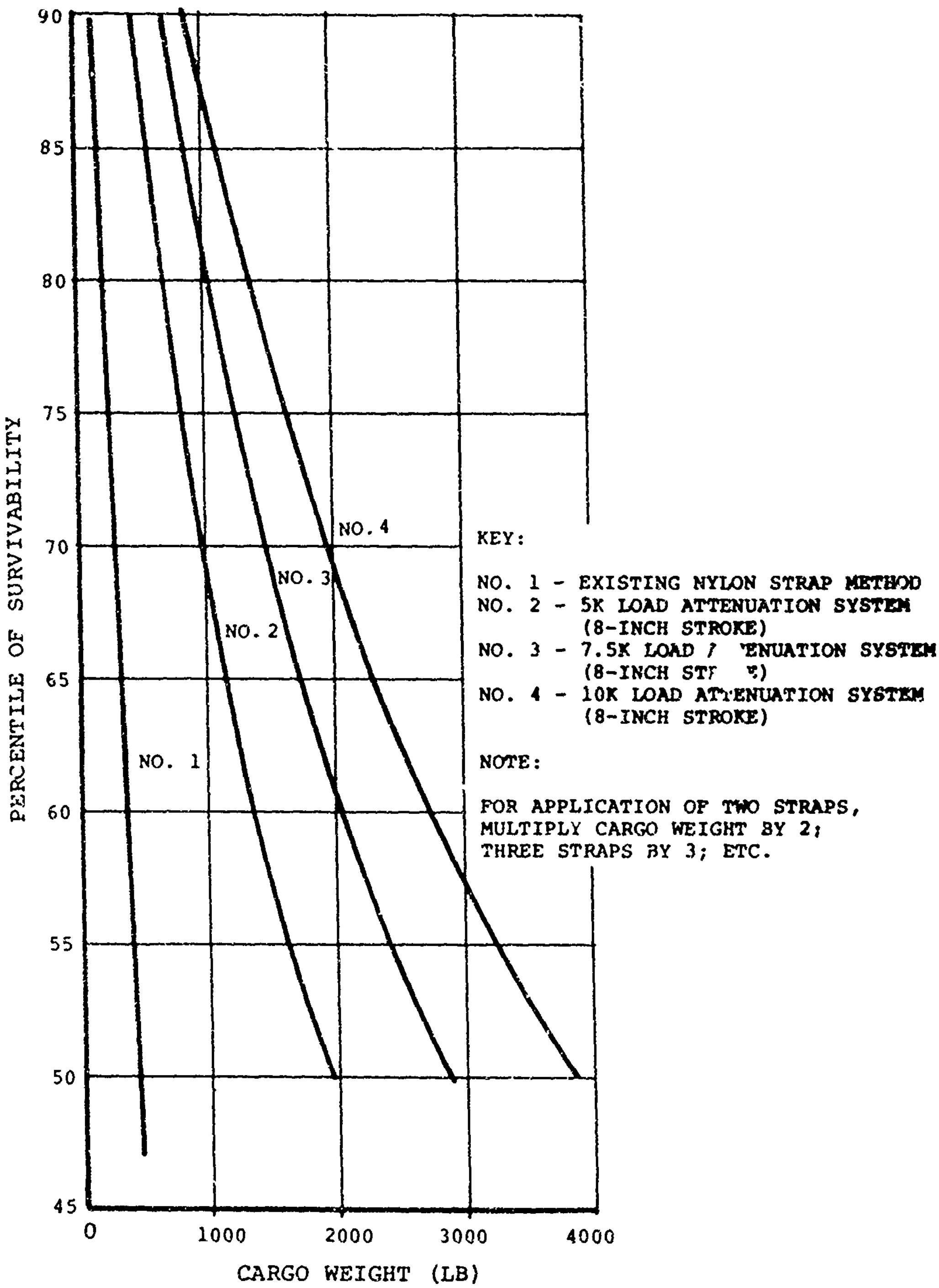


Figure 150. Percentile of Survivability Versus Cargo Weight for the Existing and New Restraint Systems Studied, Based on a Single Tiedown Strap Application Requirement for the Longitudinal Impact Direction.

For the lateral restraint direction (see Figure 151), as for the longitudinal restraint direction, the load attenuation type system is capable of restraining relatively larger cargo weights than the existing nylon strap system (at all percentile levels). Since the restraint g level for the lateral direction is much lower than the longitudinal direction at the 90th percentile level, the number of restraint devices required for the lower weight cargoes (1000 to 3000 pounds) carried in U.S. Army aircraft is relatively small for all restraint systems. Therefore, the degradation of restraint load capacity due to floor fitting locations is not normally a problem. The one major exception is the 3/4-ton truck (weighing 5660 pounds) where the existing nylon strap method requires approximately 20 straps per side and the 7.5K system 2 straps per side. (Again, when doubled around a vehicle to provide twice the capacity, each end of a strap is tied to a floor fitting.) The total number of restraint devices for a given cargo is relatively large when comparing the existing Army nylon restraint system to a load limiting restraint system, since the latter requires a relatively large number of tiedown devices when restraining to the design limits of survivability.

7.4.1 EXISTING ARMY RESTRAINT METHODS

With the use of specified Army technical manuals, which show existing techniques for restraining various size and weight vehicles, Table XXXIII was developed to show the increased survivability that can be accomplished when using a load attenuator restraint system (including a low-elastic-type strap device) instead of nylon web-type devices (already part of aircraft inventory) as a restraint system. For this study, chain devices shown in the manuals were replaced with nylon straps. The mixing of web-and-chain devices is thoroughly documented (see Reference 21) as being deficient for a restraint medium, because of the variant differences in elasticity characteristics of the two type devices and the possibility of the chain device failing due to high oscillation forces (that occur during the initial period of impact).

Existing Army techniques, as shown in the cargo restraint manuals, result in utilization of the tiedown devices for all three directions of restraint, in order to minimize the total number of devices utilized. This goal (of a minimum number of tiedown devices) is difficult to obtain because the restraint system load factors, both static and dynamic, are not proportioned to the same geometric relationship that can be established with the tiedown device, when restraining cargo. In addition, the mixing of straps and chains at different load levels and lengths greatly degrades the system. For these reasons, this technique is not applicable to either the static or dynamic criteria.

From the table, the following observations are made:

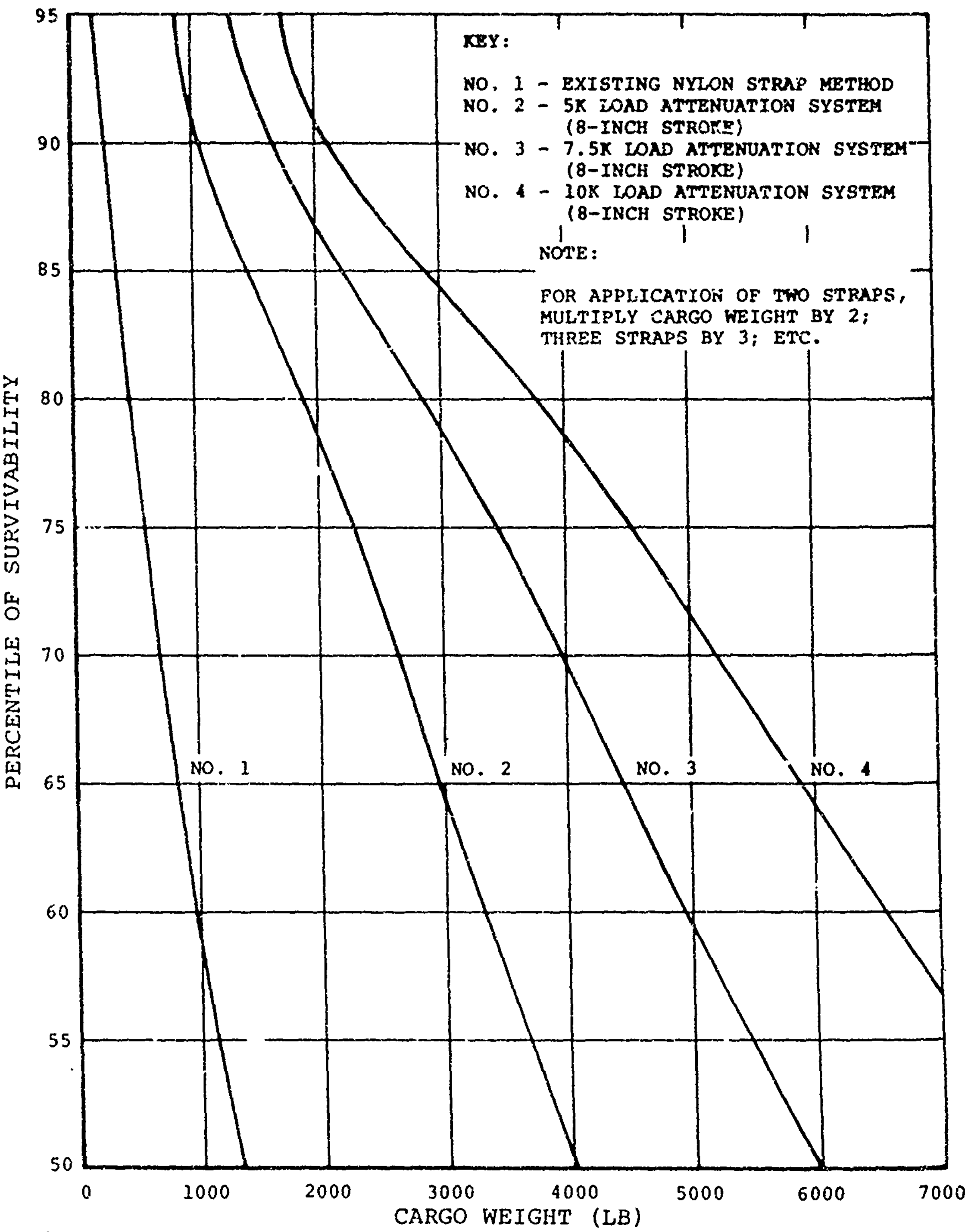


Figure 151. Percentile of Survivability Versus Cargo Weight for the Existing and New Restraint Systems Studied, Based on a Single Tiedown Strap Application Requirement for the Lateral Impact Direction.

1. The 90th percentile of survivability for the lateral restraint direction is possible when restraining the 1/4-ton trailer with the 5K and 7.5K restraint system. The existing Army restraint methods using nylon straps results in the trailer being restrained to the 58th percentile level.

2. The resultant techniques using 7.5K load attenuators will result in greater than the 90th percentile of survivability when restraining a 1/4-ton truck for aft restraint. Use of 5K load limiters results in the 81st percentile level and the existing nylon straps being degraded to the 41st percentile level or about 50 percent of the percentile level of the 5K system.

3. In general, an increase in survivability of 100 to 250 percent is realized when restraining cargo with a restraint system composed of low-elastic tiedown devices and 5K load attenuators, in place of the restraint techniques in the TM's utilizing nylon tiedown strap devices. The use of 7.5K load attenuators will further increase the survivability percentile level by 13 to 18 percent, resulting in 113 to 295 percent higher levels than the existing nylon method.

4. For the techniques displayed, the forward and aft restraint percentile levels are relatively close in magnitude for the load attenuation systems. An additional strap in the forward and aft directions could significantly increase the percentile levels. It is estimated for the 1/4-ton truck, that the 69th percentile value for forward restraint can be increased to about the 79th percentile value with the addition of one tiedown device.

5. The array of cargo shown with lateral restraint for the 7.5K load limiting system is close to the design criteria (for all practical purposes), and the array of cargo shown with lateral restraint for the 5K system is slightly lower.

7.4.2 COMBAT RESTRAINT METHODS

Combat methods for restraining cargo are aimed at utilizing a minimum number of tiedown devices to achieve multidirectional restraint within the intervals of time available. Consequently, the degree of cargo retention by a given restraint system is associated with the impact pulse imparted to the aircraft. The ideal restraint method is the use of four tiedown devices, with load attenuators for vehicles, and a four-point load limiting net attachment for mixed cargo. The survivability percentile levels which are a function of the cargo retention

g levels depend basically on the cargo weight, restraint system characteristics, and the angles between the restraint devices and the cargo and floor. Since a minimum of restraints are considered, an "idealized restraint angle concept" may be feasible for vehicle loading, where the percentile of survivability attainable from a tiedown situation is the same for both longitudinal and lateral dynamic impact directions. Use of this concept depends on the locations of the vehicle tiedown attachment and floor tiedown fitting. Since existing aircraft floor tiedown patterns are predetermined, the actual restraint angle utilized may differ somewhat from the idealized restraint angle, resulting in a restraint load a little higher in one direction than the other.

The idealized restraint pattern shown in Figure 152 is typical of the pattern that may be feasible for a 1/4-ton vehicle when tiedown fittings are located about 15 inches above the aircraft floor.

The associated load factors n for a 1/4-ton jeep (2350 pounds) pertinent to the existing Army restraint method and to 5K and 7.5K restraint systems are as follows:

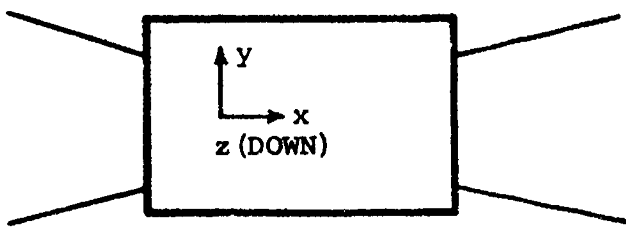
$$n_{long.} = \frac{2\ (5000)\ (0.84)}{2350} = 3.58$$ (For existing Army method using 5K system. For a 7.5K system, $n_{long.} = 5.37$.)

$$n_{lat.} = \frac{2\ (5000)\ (0.34)}{2350} = 1.45$$ (For existing Army method using 5K system. For a 7.5K system, $n_{lat.} = 2.18$.)

$$n_{vert.} = \frac{4\ (5000)\ (0.427)}{2350} = 3.65$$ (Approximately equal to the static load factor criterion of 3.75.)

The corresponding percentile levels of survivability are as follows:

Restraint Direction (Ideal Arrangement)	Percentile: Existing Army Nylon Restraint Method	5K Load Limiter Restraint System	7.5K Load Limiter Restraint System
Longitudinal	20	60	70
Lateral	25	57.5	75



TRUE TIEDOWN LENGTH
OF 35 INCHES

x = 29.4 IN.
y = 11.9 IN.
z = 15 IN.

WITH P THE RESTRAINT LOAD,
THE LOADS IN THE THREE
DIRECTIONS ARE

$$P_x = 0.84P$$
$$P_y = 0.34P$$
$$P_z = 0.427P$$

Figure 152. Plan View of Idealized Restraint Pattern.

These values indicate that for a 1/4-ton jeep restrained by a minimum tiedown system, the load limiting system provides relatively high percentile levels of survivability, compared to the existing Army restraint methods. A further analysis was undertaken for the same vehicle restrained according to TM 55-2320-218-10-2 (Appendix III) utilizing four restraint devices instead of eight. The restraint method specified in the manuals does not conform to the idealized restraint angle concept previously discussed.

The resultant load factors are:

n_{fwd} = 4.12 (For existing Army method using 5K system. For 7.5K system n_{fwd} = 6.18.)

n_{aft} = 3.96 (For existing Army method using 5K system. For 7.5K system n_{aft} = 5.94.)

$n_{lat.}$ = 0.89 (For existing Army method using 5K system. For 7.5K system $n_{vert.}$ = 1.34.)

$n_{vert.}$ = 1.85 (Less than the static load factor criterion of 3.75.)

The corresponding percentile levels of survivability are as follows:

Restraint Direction (Technical Manual Arrangement)	Percentile		
	Existing Army Nylon Restraint Method	5K Load Limiter Restraint System	7.5K Load Limiter Restraint System
Longitudinal	25.5 Fwd 24 Aft	63.5 Fwd 62.5 Aft	73 Fwd 74 Aft
Lateral	17	40 (estimated)	55

When load attenuators are used to restrain a 1/4-ton truck, a decrease of 10 percent in the percentile levels of survivability can be expected, comparing the minimum tiedown procedure data above to the tiedown procedure depicted in the Army manuals (Table XXXIII and Figure 183). When existing Army nylon strap restraint methods are used for the same tiedown procedure, virtually no change in the percentile level for forward restraint is realized. This is attributed to load degradation resulting from variations in the length of devices used for restraint in a given restraint direction. The four tiedown devices used

for forward restraint (Figure 184) are practically equivalent, loadwise, to two restraint devices. For the aft restraint direction, when existing restraint methods are used, a decrease of about 35 percent is indicated. In some instances Army manuals are already utilizing the minimum tiedown concept. For example, this concept is applied in restraining the M100 1/4-ton trailer and the M107 water trailer (see Figures 184 and 185).

Further adaptation of the minimum tiedown procedure was explored for pertinent cargo and is presented in Table XXXIV in terms of percentile of survivability for both the 5K nylon restraint system and the 7.5K restraint system. It is concluded from the data that, with the proposed system, cargo weights as high as 2500 pounds can be restrained by minimum tiedown devices to the 75th percentile level of survivability. Obviously, when lighter cargo is restrained under the same tiedown pattern, higher percentile levels will result. Percentile levels for cargo weights above 2500 pounds will, of course, be lower. However, an additional strap in a given direction (as noted earlier in this section) could significantly increase the levels of survivability for a given cargo weight. Consequently, it can be emphatically stated that a great deal of protection can be afforded the crew during combat operations by employing minimum restraint techniques.

TABLE XXXIV. COMBAT PERCENTILE OF SURVIVABILITY FOR GIVEN CARGO AND RESTRAINT SYSTEMS USING FOUR TIEDOWN DEVICES (BASED ON DYNAMIC CRITERIA)

Cargo Type	Cargo Weight (lb)	Percentile of Crash Survivability for Dynamic Criteria			
		Existing Nylon Straps as Restraint System (Replacing Chains with Nylon Straps of 5K Capacity)		Low-Elastic Restraint Devices with 7.5K Load Attenuators	
		Restraint Direction		Restraint Direction	
		Long.	Lat.	Long.	Lat.
M100 1/4-ton trailer	1090	37.5	58	87	90
M107 water trailer	2260	25	32	75	84
M151 1/4-ton truck	2350	20	25	70	75
M170 1/4-ton ambulance	2963	15	20	67	66
M37 3/4-ton truck	5560	6.5	14.5	45	47

8. PRELIMINARY DESIGN

A preliminary design of the 7.5K tube-ball load limiter device as a retrofit to the CH-47 helicopter structure is presented in this section.

The primary structural components are the tube-ball device, a support fitting bridging the floor frame at the tiedown locations, two structural plates added to the helicopter floor frame outer cap at eleven frame locations, and a Dacron tiedown device to restrain the cargo.

The following paragraphs include a description of the retrofit design, an analysis to confirm the integrity of the structural components, and methods of applying the load attenuation concept to future aircraft design.

8.1 DESIGN DESCRIPTION

7500-Pound (7.5K) Load Limiter (See Figure 153)

The load limiter device was designed on a retrofit basis capable of being installed with either the fixed or isolated floor structure. Of the 89 units considered, 85 can be installed with the recommended 8-inch stroke capability. Because of shallow frame depths, the remaining four tiedown locations will result in installation of 7-inch stroking devices. In addition, six existing 5K tiedown fittings could not readily be converted to 7.5K units because of structural limitations. If these fittings are needed for other purposes (such as securing a personnel safety harness), "restrictive use" notes should be entered in the appropriate pilot and maintenance handbooks and placarded to the aircraft at these locations.

Each load attenuator will be installed in an eccentric position from the floor frame centerline. Where practical, a staggered load limiter pattern along each frame was utilized to offset the frame torsional moments that will result from vertical component tiedown loads when alternate tiedown locations are used for restraint. However, the cargo load supporting structure is capable of reacting the torsional moment indicated in the SUPPORTING STRUCTURE LOADS ANALYSIS in Section 8.3.

The load limiter device was designed in envelope form leaving the component details to the manufacturer. This was necessary since the original AAE tube-ball device capacity was upgraded to 7.5K from 5K. An analytical approach is presented in Section 8.2 to aid in the development of this unit.

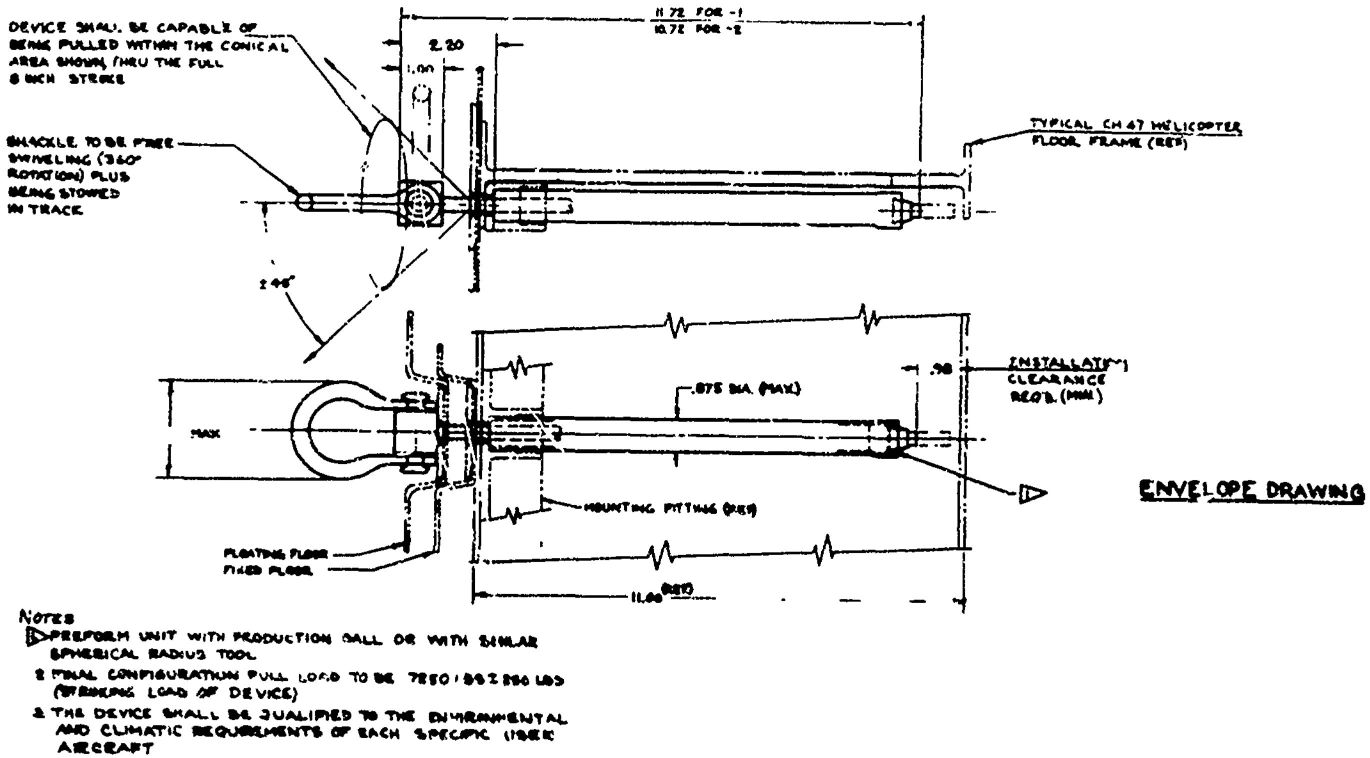


Figure 153. 7.5K Capacity Tube-Ball Load Limiter.

Installation in the aircraft is easily accomplished by passing a cable-fitting assembly from the floor side through a pre-drilled hole in the frame and support structure. Then the tube is passed over the cable from the underside of the floor, followed by the ball which is held by the installation of a washer and nut.

Support Fitting (See Figure 154, Detail G.)

This fitting is nestled under the inner cap of the floor frame at each tiedown location to increase the frame stiffness. In addition, the fitting helps to maintain the load limiter in its installed position.

Floor Frame Modification (See Figure 154, Detail A.)

Aluminum plates (doublers, Part No. SK21883-19) attached to the outer cap of 11 floor frames are required. See the FLOOR FRAME ANALYSIS in Section 8.3.

Cargo Tiedown Device (See Figure 155.)

The material properties of the webbing for the tiedown device are to be commensurate with the low-elastic properties of Dacron. A high strength Dacron webbing will result in a more efficient restraint system. The recommended cargo tiedown device is of 10,000 pound capacity.

8.2 LOAD LIMITER ANALYSIS

Pertinent Parameters Defined

R_s = spherical radius of ball

R_o = outside tube radius

R_i = inside tube radius

t = tube thickness

f_u = friction coefficient between ball and tube

f_e = equivalent friction coefficient between ball and tube

a = length of contact between ball and tube

θ = angle of arc of length a

ρ = internal pressure in tube

F_{ty} = tensile yield strength of tube material

P_c = axial contact force of ball and tube

A_f = area over which the internal pressure acts

P = load limiter pull load intensity

Derivation

The equation that relates the wall stresses in a cylinder due to uniform pressure on the inner surface is:

$$\sigma = \frac{\rho (R_i^{2} + R_o^{2})}{R_o^{2} - R_i^{2}} \tag{37}$$

with $\sigma = F_{ty}$

Then,

$$\rho = \frac{F_{ty}(R_o^{2} - R_i^{2})}{(R_i^{2} + R_o^{2})} \tag{38}$$

Also,

$$P = P_c + f_u \rho A_f = f_e \rho A_f \tag{39}$$

where $f_e = \frac{P_c}{\rho A_f} + f_u$

and

$$A_f = \int 2\pi \Gamma dx \text{ (See Figure 156)} \tag{40}$$

where $\Gamma = R_s \cos\theta$

$dx = R_s \cos\theta \, d\theta$

Then,

$$A_f = \int_o^{\theta} 2\pi R_s^{2} \cos^{2}\theta \, d\theta \tag{41}$$

$$A_f = 2\pi R_s^{2}(1/2 \, \theta + 1/4 \sin 2\theta) \tag{42}$$

where $\theta = \cos^{-1} \frac{R_i}{R_s}$

Determination of f_e

For this analysis, the equivalent coefficient of friction factor f_e was obtained below from the AAE 5K load limiter data, which includes painting the tube inside diameter with zinc chromate primer. From Equation (38),

where F_{ty} = 127,500 psi

R_o = 0.313 in.

R_i = 0.254 in.

then

$$\rho = 127,500 \left[\frac{(0.313)^2 - (0.254)^2}{(0.313)^2 + (0.254)^2} \right] = 26,300 \text{ psi} \quad (43)$$

From Equation (39) and where R_s = 0.284 in., then

$$\theta = \cos^{-1} \frac{0.254}{0.284} = \cos^{-1} 0.894 = 26.5° \text{ or } 0.462 \text{ radians} \quad (44)$$

$$A_f = 2\,\pi (0.284)^2 \left[\frac{0.462}{2} + \frac{\text{SIN } 53.0°}{4} \right] = 0.218 \text{ sq in.} \quad (45)$$

$$f_e = \frac{5000}{26,300\ (0.218)} = 0.873 \quad (46)$$

<u>Example Calculation for 7.5K Load Limiter</u>

Assume a 3/4-inch tube of 0.065 wall thickness heat-treated to 160,000 psi. From Equation (38),

where F_{ty} = 141,000 psi

R_o = 0.375 in.

R_i = 0.310 in.

then

$$\rho = 141,000 \left[\frac{(0.375)^2 - (0.310)^2}{(0.310)^2 + (0.375)^2} \right] = 26,550 \text{ psi} \quad (47)$$

From Equation (39) and where R_s = 0.347 in.,

then

$$\theta = \cos^{-1} \frac{0.310}{0.347} = 0.462 \text{ radians or } 26.5° \quad (48)$$

$$A_f = 2\pi\ (0.347)^2\ (0.431) = 0.3255 \text{ sq in.} \quad (49)$$

$$P = 0.873\ (0.3255)\ (26,550) = 7,520 \text{ lb} \quad (50)$$

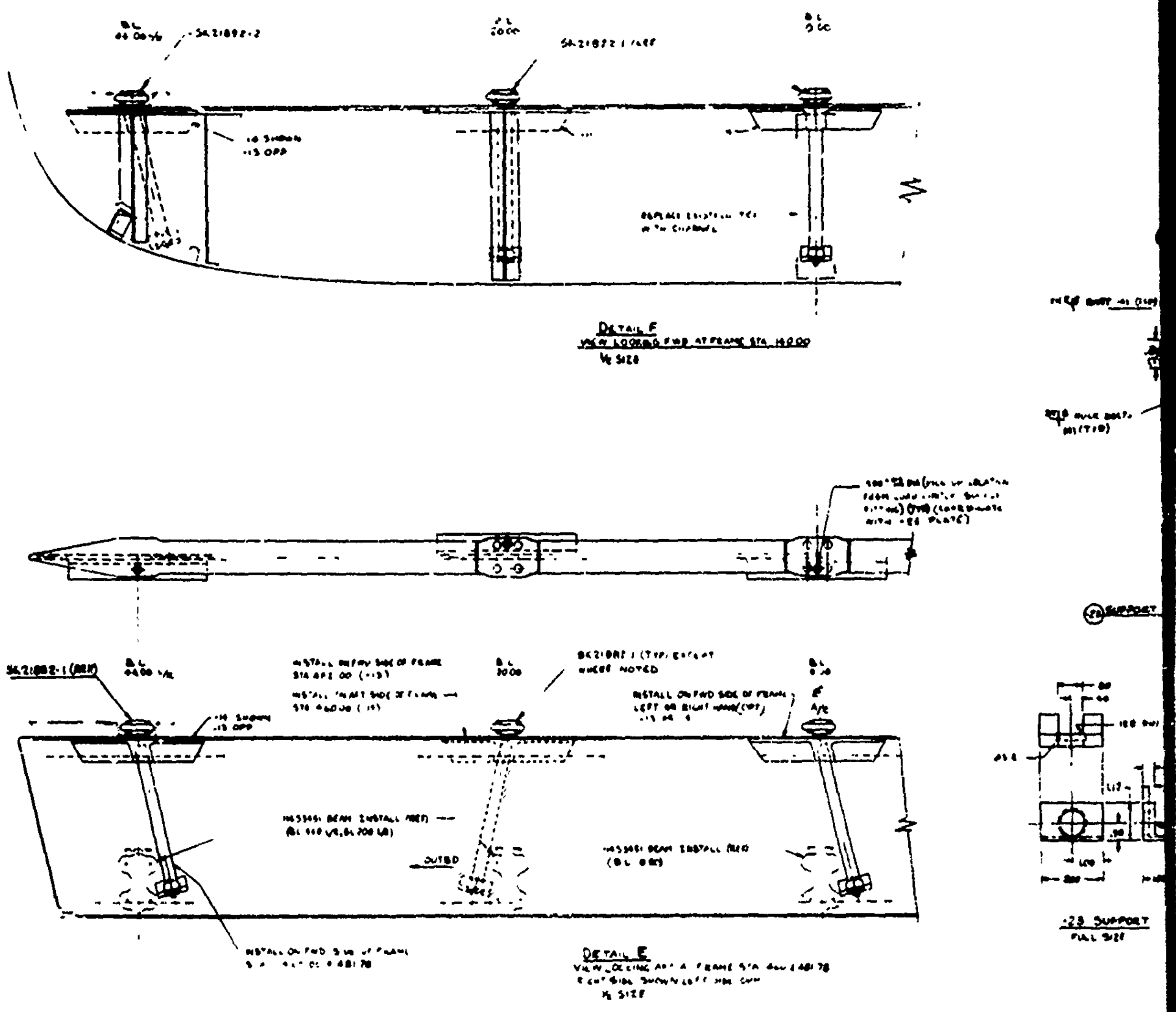
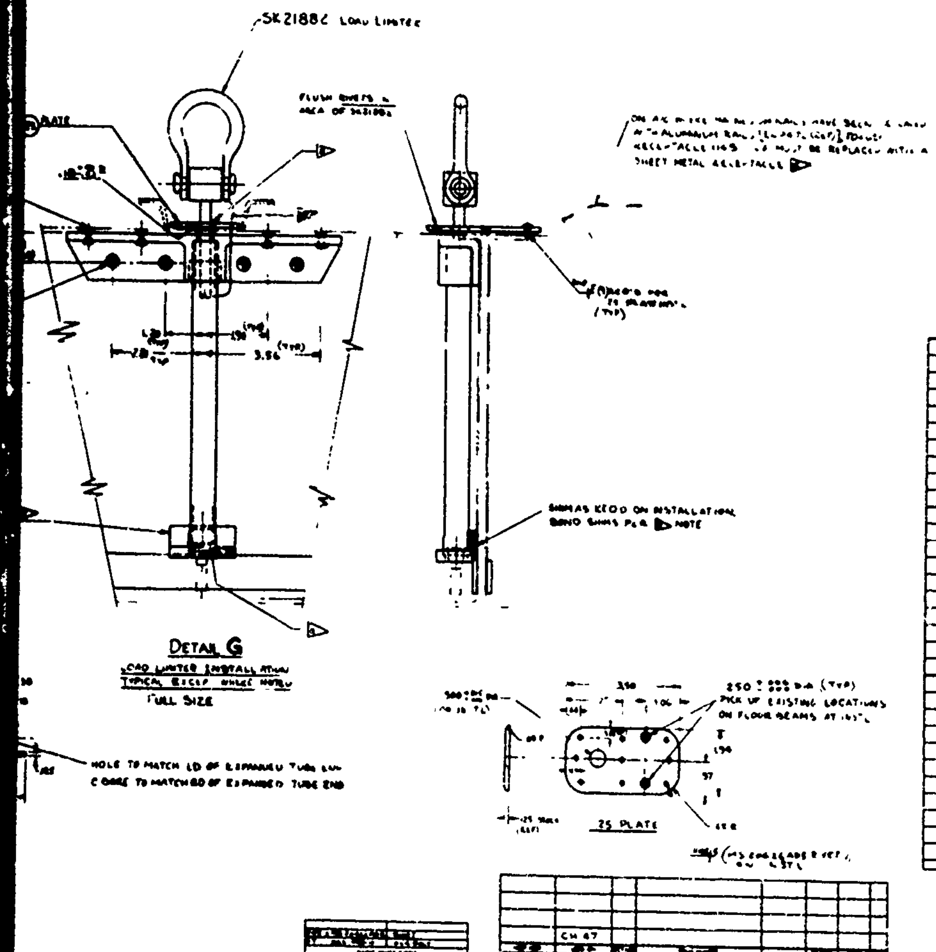


Figure 154. 7.5K Tube-Ball Load Limiter Installation (Sheet 1 of 2).



NOTES

GENERAL

1. INSTALLATION OF SK21882 BALL TUBE LOAD LIMITERS ARE SHOWN IN DETAILS A THRU G

DETAIL A SHOWS A TYPICAL FRAME WITH DESIRED STAGGERED LOAD LIMITER INSTALLATION

DETAIL B SHOWS A VIEW OF FRAME STATIONS 180.00 & 200.00 AT BUTT LINE 44.00 L/R WITH LOAD LIMITER CANTED TO CLEAR STRUCTURE

DETAIL C SHOWS A VIEW OF FRAME STATION 260.00 AT BUTT LINE 44.00 L/R, USING A SPECIAL LOAD LIMITER SUPPORT FITTING, INCORPORATING A FRAME SPLICE ANGLE

DETAIL D SHOWS A VIEW OF STATION 120.00 WITH A REDUCED STROKE LOAD LIMITER CANTED AT BUTT LINE 44.00 L/R AND STAGGERED LOAD LIMITERS RAN VERTICALLY AT BUTT LINES 20.00 L/R & 0.00.

DETAIL E IS A VIEW OF FRAME STATIONS 420.00 & 480.00, WITH THE LOAD LIMITERS CANTED TO CLEAR INTERCOSTAL STRUCTURE BETWEEN FRAMES

DETAIL F IS A VIEW OF FRAME STATION 140, SHOWING A REDUCED STROKE LOAD LIMITER CANTED AT BUTT LINE 44.00 L/R AND LOAD LIMITER INSTALLATION MOUNTED VERTICALLY AT BUTT LINES 20.00 & 0.00

DETAIL G SHOWS A FULL SIZE DETAIL OF A TYPICAL BALL TUBE LOAD LIMITER INSTALLATION FOR VERTICAL OR CANTED REQUIREMENT

Qty	Part No.	Nomenclature	Material / Specification		
[illegible]	NAS1468-10	LOCK BOLT			
[illegible]	MS20426AD5	RIVET			
[illegible]	-25	PLATE	[illegible]	77	[illegible]
[illegible]	-23	SUPPORT	[illegible]		
[illegible]	-21	FORGING	[illegible]	77	
22	-19	DOUBLER	[illegible]	77	
1	-18	FITTING	MAKE FROM -21 FORGING		
1	-17	FITTING			
1	-16	FITTING			
1	-15	FITTING			
8	-14	FITTING			
8	-13	FITTING			
64	SK21883-11	FITTING	MAKE FROM -21 FORGING		[illegible]
4	-2	LOAD LIMITER			
38	SK21882-1	LOAD LIMITER			
	SK21883-1	INSTALLATION			

LIST OF MATERIAL

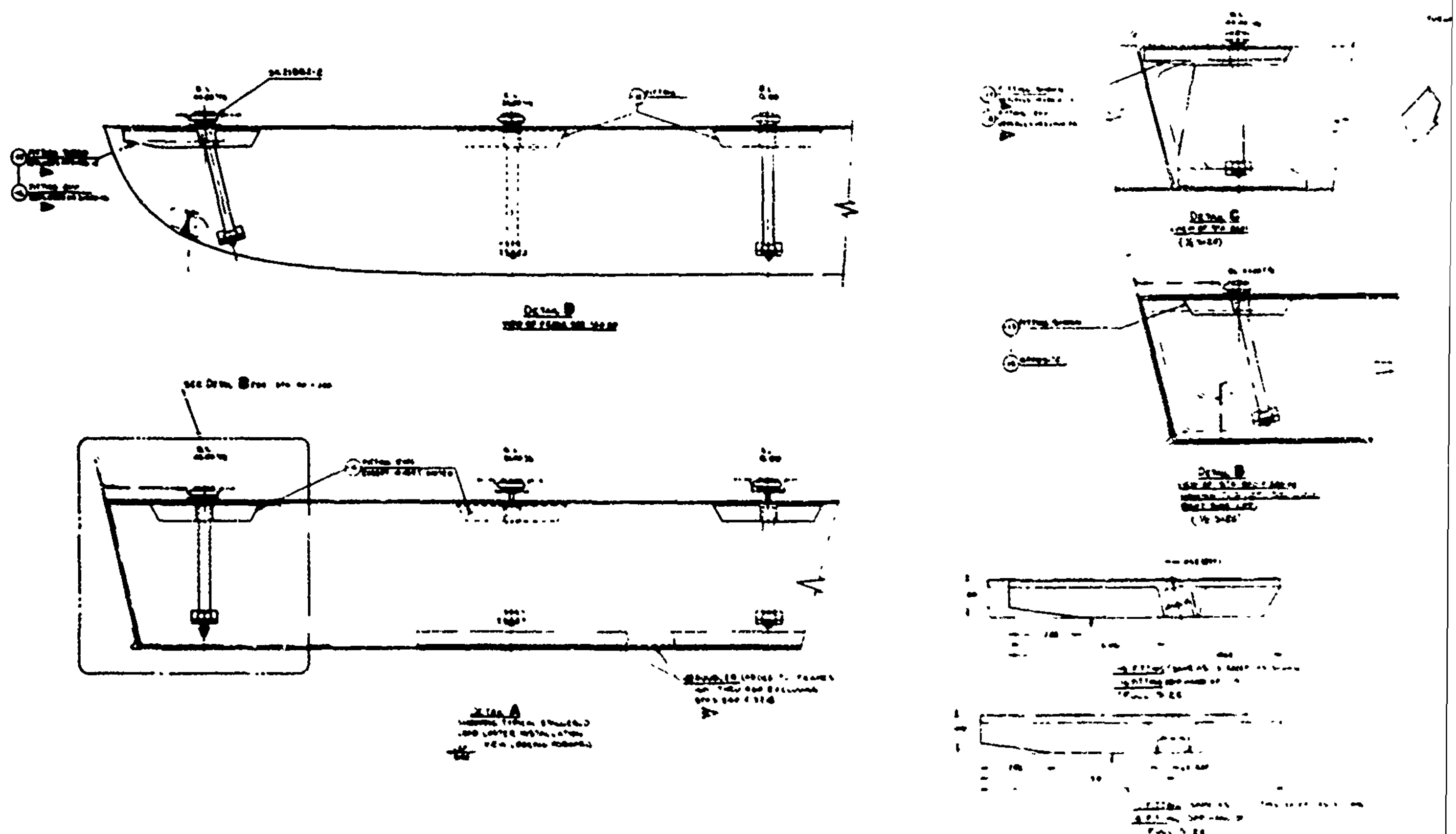
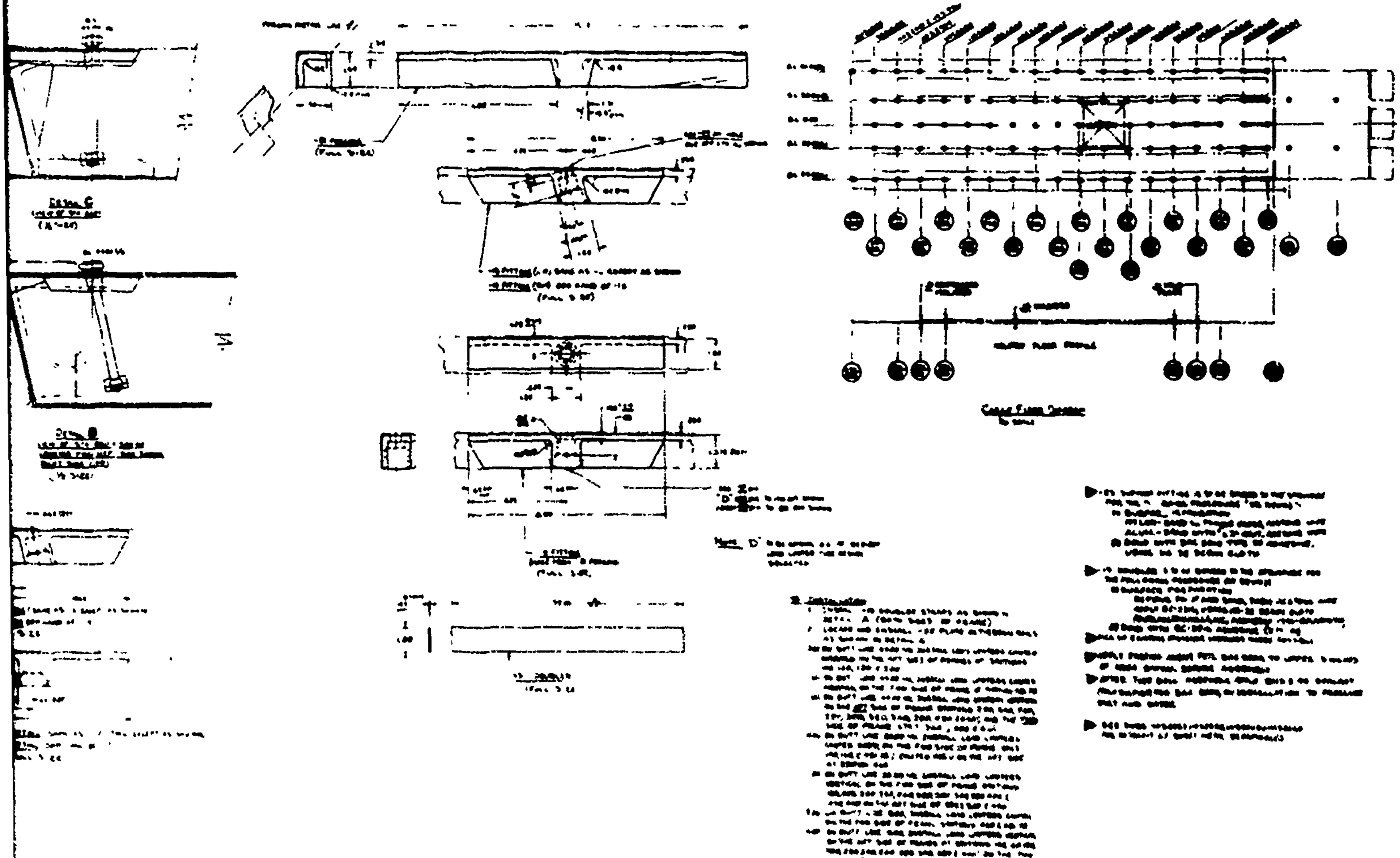


Figure 154. Continued (Sheet 2 of 2).

A



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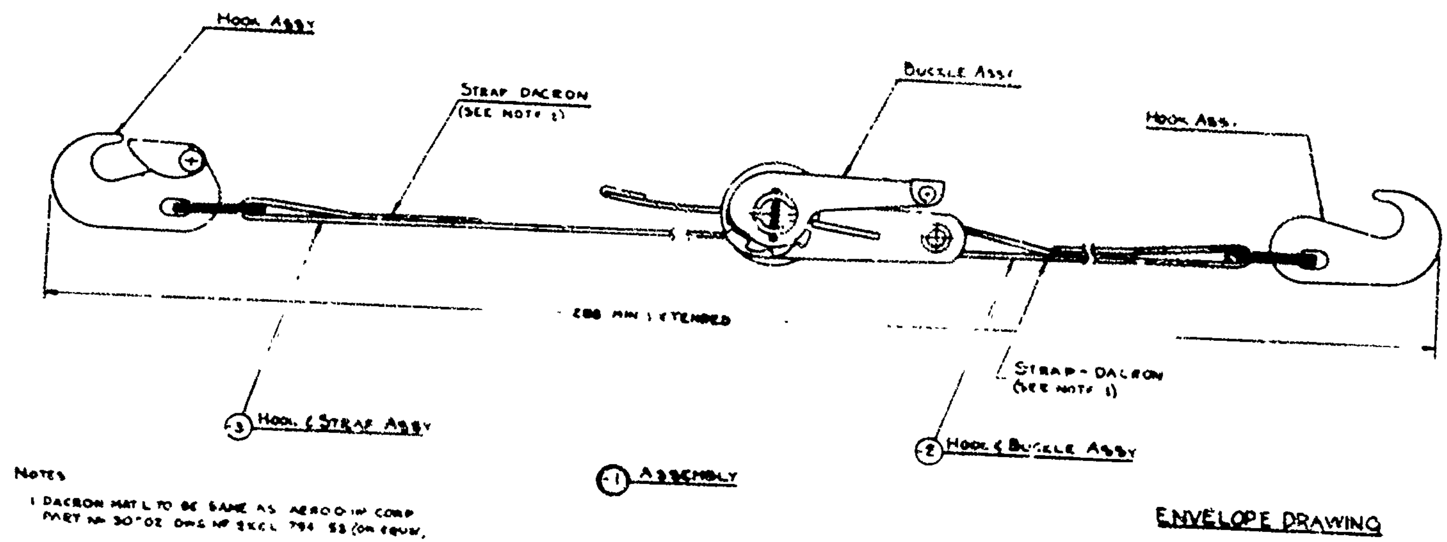

Figure 155 Assembly Strap Cargo Tiedown, 10K Capacity.

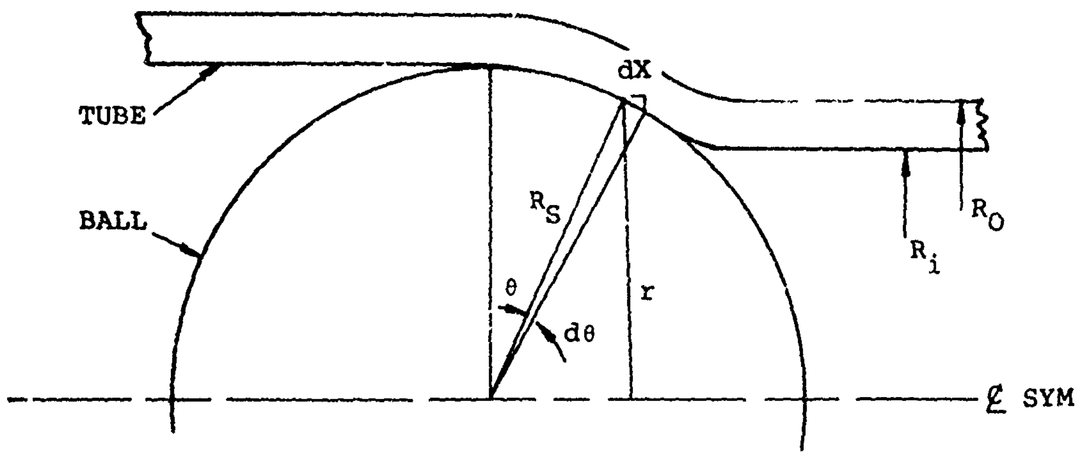

Figure 156. Tube-Ball Configuration.

8.3 AIRFRAME STRUCTURAL ANALYSIS

SUPPORTING STRUCTURE LOADS ANALYSIS

The purpose of this section is to show descriptively how the supporting structure reacts to the tiedown loads. The supporting structure consists of floor frames, floor-to-frame attachments, and floor rails (see Figure 157).

As previously mentioned, the floor was designed with isolated and fixed sections (relative to the floor frames). The isolated floor section floor-to-frame attachments consist of bolt and spacer combinations to limit the vertical floor extension (see Figure 159); whereas the fixed floor section is bolted in proximity with the floor frame. The existing design includes four attachments per tiedown fitting. However, incorporation of the load limiter concept will result in the elimination of two attachments. Because of these similarities (between the fixed and isolated floor sections), the isolated floor section was utilized for the following analysis.

Analysis

Two basic loading conditions are considered: (1) the restraint load as applied at an angle of 45 degrees from the helicopter's vertical axis toward the longitudinal axis, and (2) the restraint load as applied in a vertical up direction (parallel to the helicopter's vertical axis).

For the first condition, the isolated floor will reseat on the frame when the cargo restraints are preloaded during the tiedown operation and when the cargo is located near the tiedown fitting (Figure 157). However, for the vertical loading condition, the isolated floor will be considered in its full vertical extended position (even though it is more than likely that this condition will result in the cargo being loaded near the tiedown location.)

The analysis is presented as follows:

1. Restraint Load Applied at 45°

   This load analysis is shown diagrammatically in Figures 157 and 158. In Figure 157, the structure is shown with the vertical and horizontal component tiedown loads based on a load of 7500 pounds at an angle of 45 degrees to the vertical. The vertical component load (5300 pounds) will apply a bending moment and a twisting moment to the frame. However, the twisting moment will result in a differential bending load of 5300 (0.44)/(10), or 233 pounds, at the frame caps (see Figure 158). The differential

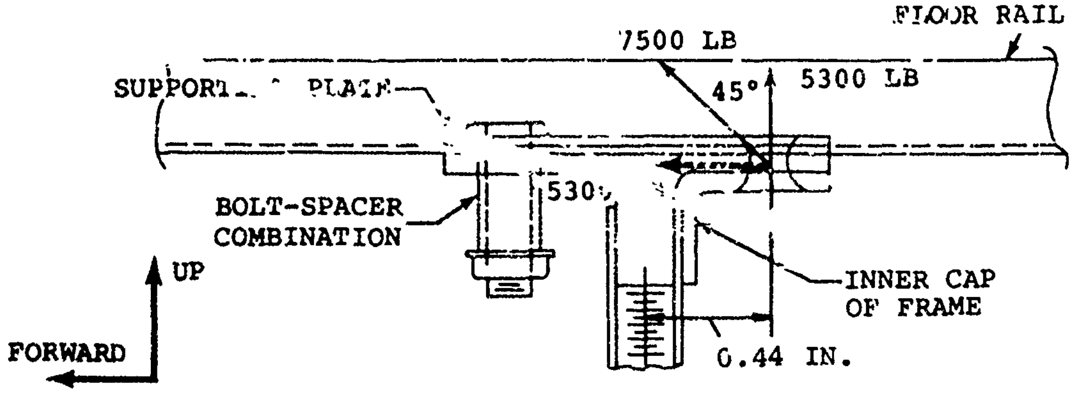

Figure 157. Supporting Structure Loads, Isolated Floor Rail Seated on Floor Frame, 7.5K Restraint Load Applied at a 45-Degree Angle.

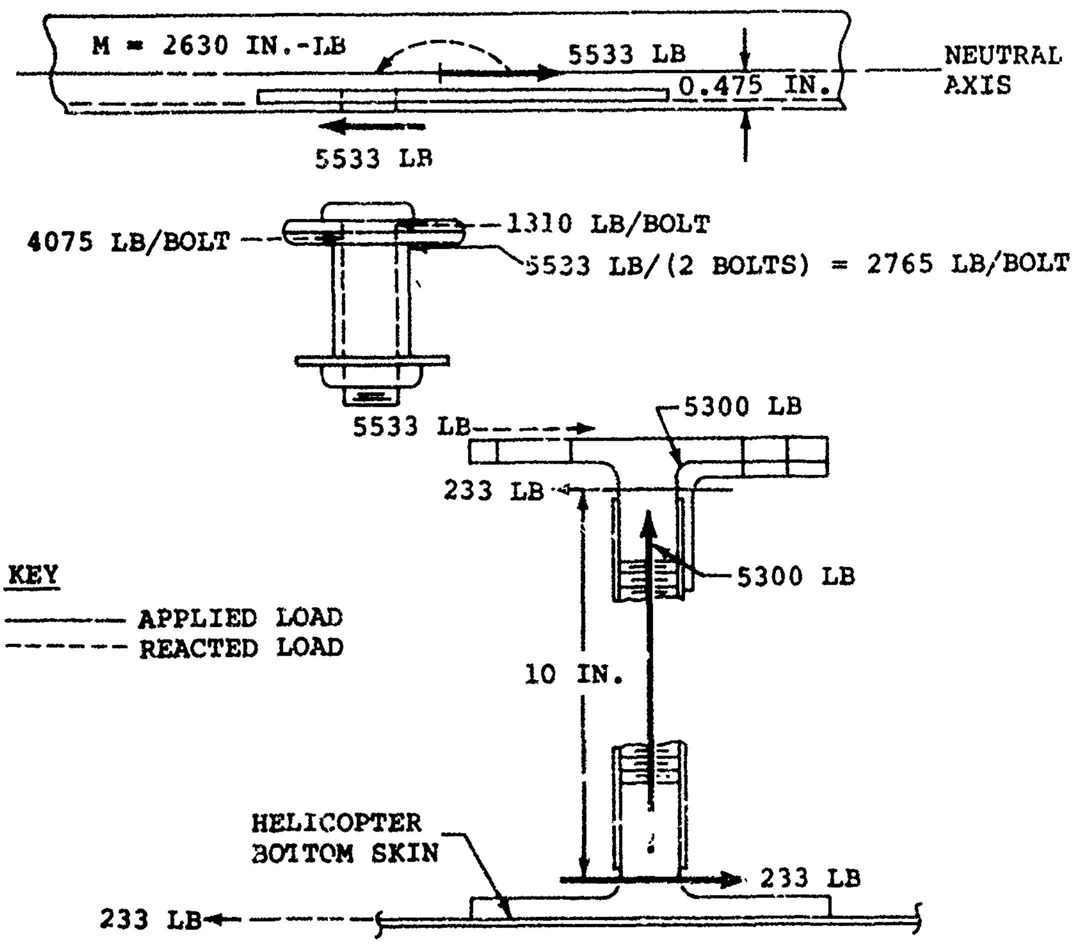

Figure 158. Supporting Structure Loads, Isolated Floor Rail Seated on Floor Frame, Free Body Diagrams of Structure and Loads.

bending loads will be reacted by the bolt-spacer combination at the inner cap and by the aircraft skin at the bottom cap location. At the inner cap, the bolt and spacer combination will transfer its corresponding load to the floor rail which results in a reacting moment of 2630 inch-pounds. A floor analysis report (Reference 43) indicates that this moment value is of lower intensity than the designed value and is therefore not critical. The reacted load at the bottom skin location is low when compared to the skin capacity. Given a 0.020-inch-thick skin, of unit width, made of aluminum material (of 70,000 psi ultimate tensile strength), the allowable skin load is 70,000 x 0.020 x 1.0, or 1400 pounds.

2. Restraint Load Applied Vertically

This analysis is similar to the one discussed above; consequently, the presentation will be brief.

The restraint load will result in a torsional moment on the structure which will act as differential bending in the frame caps. The bolt spacer will act as a bending member to transmit the inner cap load to the floor structure. The skin along the bottom of the helicopter will react the outer cap load (see Figures 159 and 160).

FLOOR FRAME ANALYSIS

To utilize 7.5K load limiters in place of the existing 5K and 10K tiedown fittings, additional structure must be added to the outer cap of approximately ten floor frames. An analysis is presented below to estimate the additional cap area and the corresponding length required. It is assumed that five 7.5K load limiters are operating simultaneously (see Figure 161).

Analysis

1. Additional Cap Area Required

Given the following conditions:

a. Maximum moment M_L is $7.5^k \left(6.5 + 30.5 + \frac{101.0}{4}\right)$, or $466^{in.-k}$.

b. Outer cap compression load $= \frac{466}{10.25} + \frac{4.68}{2} = 47.74^k$.

c. Area (T-section + skin) = 0.48 sq in.

Then, additional outer cap area is (47,740/70,000) - 0.48, or 0.212 sq in. (for 7075-T6 matl).

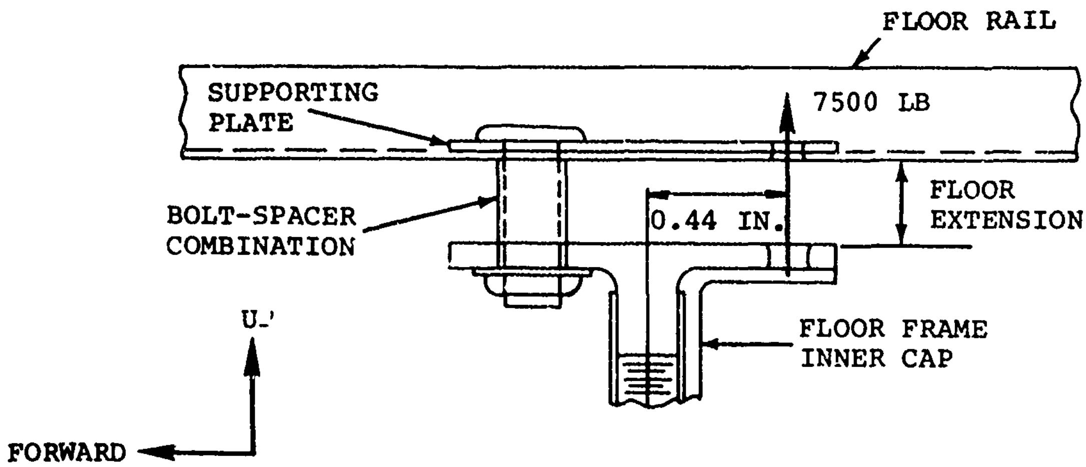

Figure 159. Supporting Structure Loads, Isolated Floor Rail Fully Extended Above Floor Frame, 7.5K Restraint Load Applied Vertically.

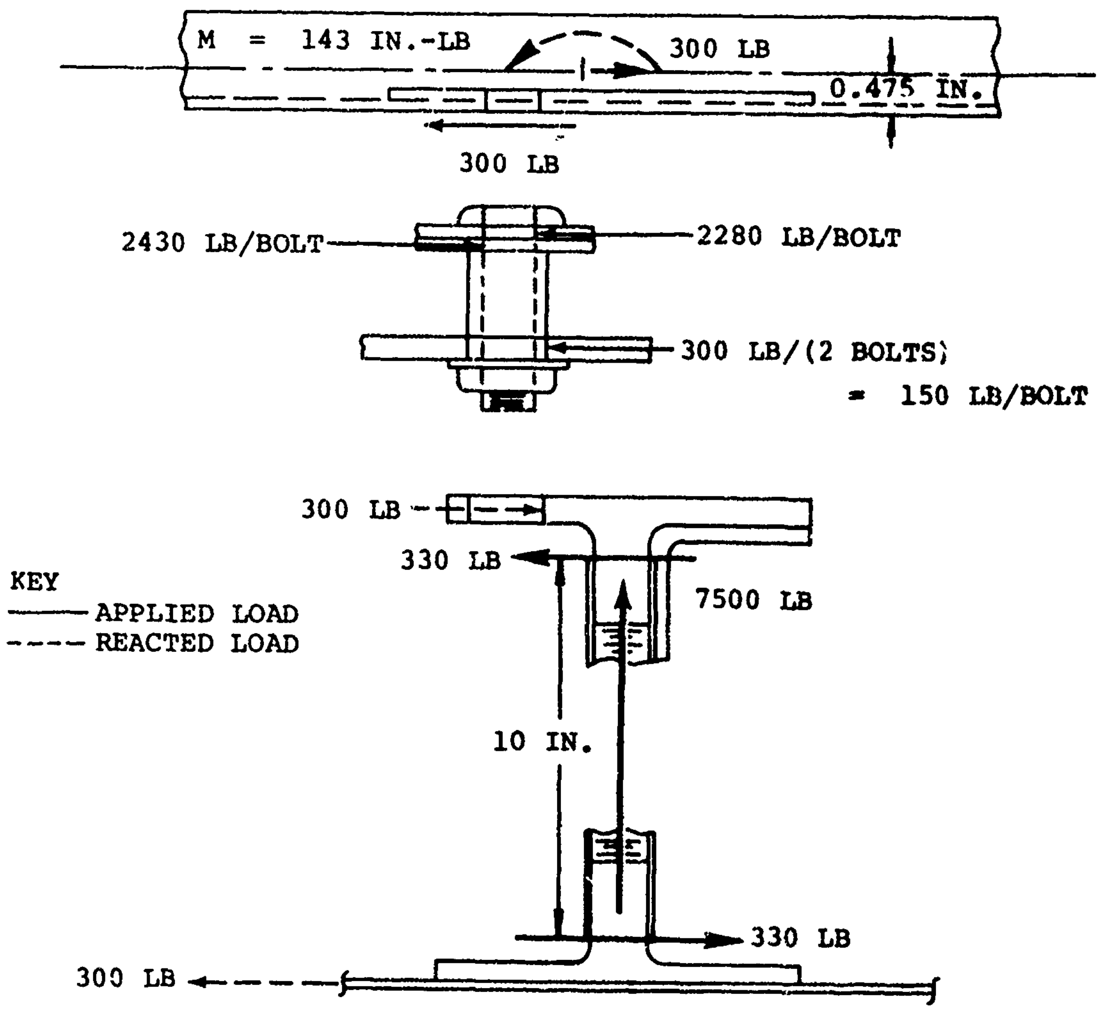

Figure 160. Supporting Structure Loads, Isolated Floor Rail Fully Extended Above Floor Frame, Free Body Diagrams of Structure and Loads.

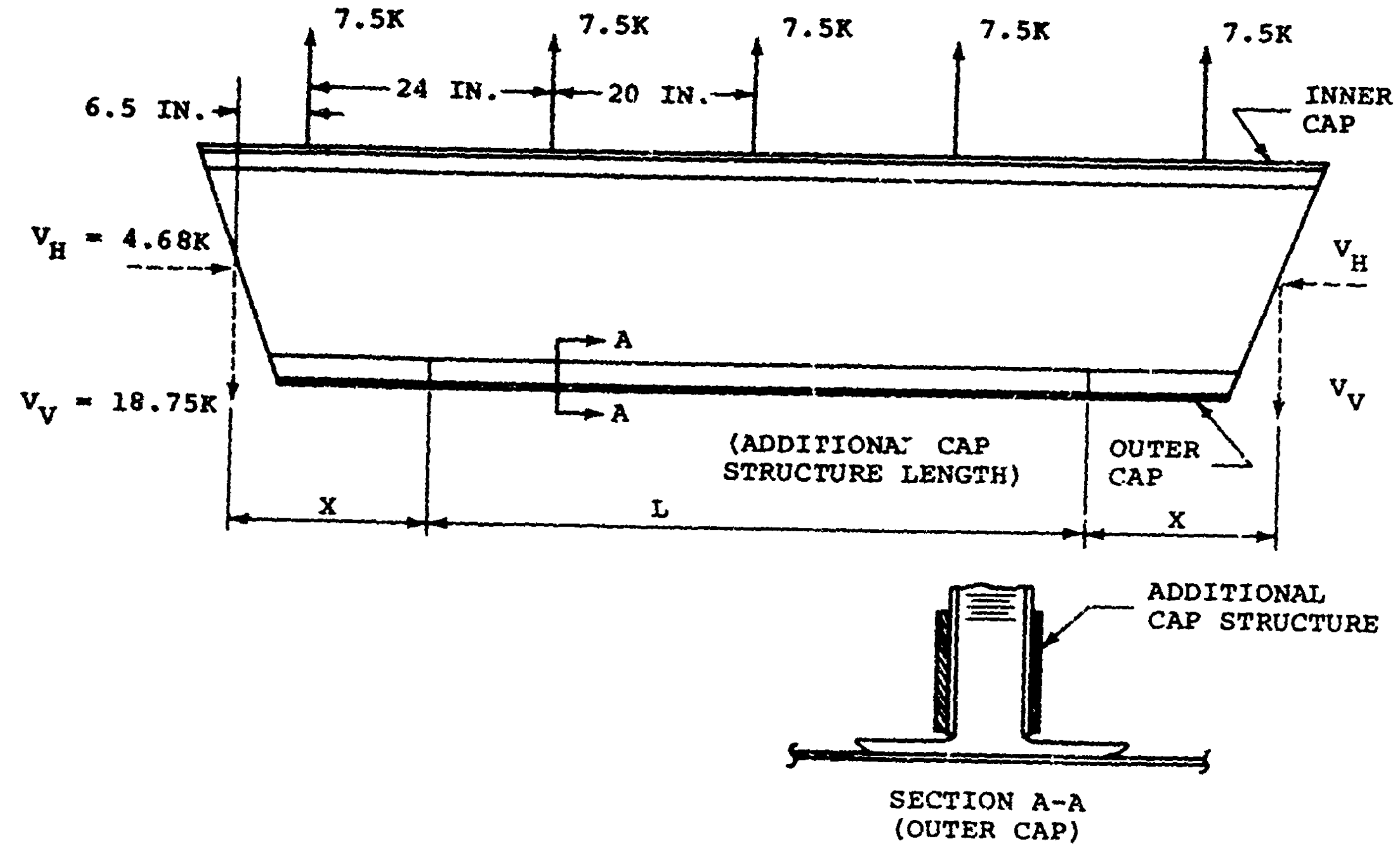

Figure 161. Typical Floor Frame With 7.5K Tiedown Loads.

2. Length of Required Cap Area

Given the following conditions:

a. Bending moment at maximum stress level for existing structure is [70,000 (.48) - 2360] 10.25, or $320^{in.-k}$.

b. The length (x) in which the beam is capable of reacting this moment is 320 = 18.75(x) - 7.5(x-6.5), or x = 24.1 inches.

Then the required length L of additional structure is [101.0 - 2(24.1)], or 52.8 inches.

SUPPORT FITTING ANALYSIS

Because of the load attenuator installation clearance, the required hole in the floor frame cap flange will result in a relatively short edge distance as compared to hole diameter (see Figure 162). Consequently, the load carrying capacity of the pertinent structure will be decreased substantially. The purpose of the support fitting is to supplement this condition and to transmit the tiedown load to the cap section. For this analysis, the flange portion (shown shaded in Figure 162) is assumed to be ineffective. Also, the 7.5K tiedown load applied in a vertical-up direction is considered to be prevalent.

Fitting Strength

Given the following conditions:

1. Rectangular shaped section 1.5 inches in width and 0.25 inch thick (location A-A of Figure 163)

2. Section modulus Z of 1.5 $(0.25)^2/6$, or 0.013 cubic inch

3. Bending moment M of 7500 (0.315-0.125), or 1425 inch-pounds

Then, bending strength f_b is M/Z or 1425/0.013, or 110,000 psi.

From Reference 51, the allowable bending strength for 7075-T6 extrusion is 115,000 psi. The margin of safety is (115,000/110,000)-1, or + 0.04.

The fitting acts as a simply supported beam which is subjected to bending stresses (see Figure 163).

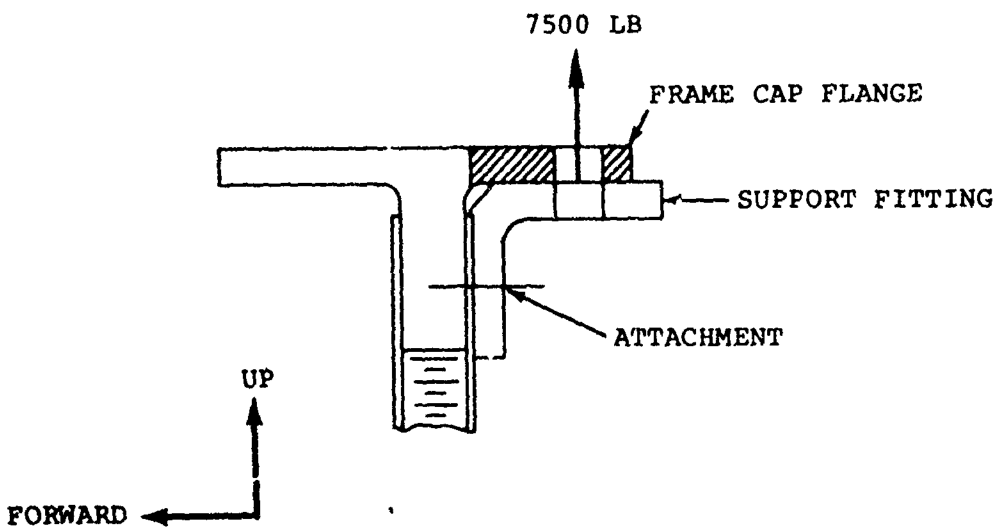

Figure 162. Support Fitting and Frame Inner Cap.

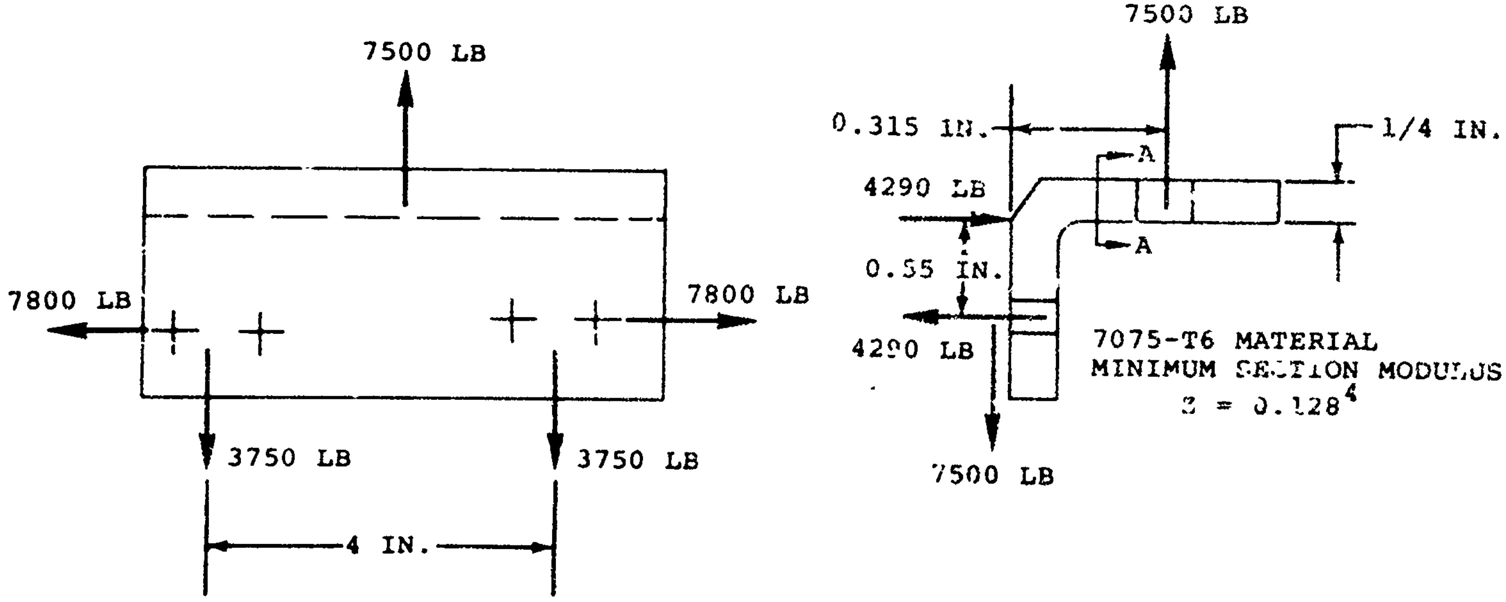

Figure 163. Support Fitting with Load Balance.

Where bending moment M at the beam centerline is 7500(4)/(4), or 7500 inch-pounds, and maximum bending stress is 7500/0.128, or 58,700 psi, and allowable bending stress is 115,000 psi, then the margin of safety is (115,000/58,700)-1 or + 0.96.

Attachments

The attachments consist of four 1/4-inch steel lockbolts and are subjected to both tension and shear loads. These values are computed and compared to the allowable strength capacities, in terms of a margin of safety calculation, as follows:

1. Tension load per bolt P_T is 4290/4 or 1070 pounds.

2. The shear load is the vector sum of the 7500-pound tiedown load and the cap tension load capacity of that portion of the flange previously considered ineffective (cross-section area of 0.100 square inch). Then, the shear load per bolt V is 7500/4 $+\!\!\!\rightarrow$ 78,000(.100)/2, or 4300 pounds.

3. The allowable tension and shear loads are 2040 pounds and 4650 pounds, respectively. From Reference 5, the margin of safety is:

$$\frac{1}{(4330/4650)^{10} + (1070/2040)} - 1 = \underline{0}$$

EFFECTS OF FRICTION

An impending or static friction force develops between the tube-ball cable (attaching shackle to ball, Figure 153) and the tiedown rail plate (Figure 154, Detail G) prior to the stroking of the load limiter device. This static friction force (shown in Figure 164) is dependent on the coefficient of static friction and the angle of contact between these parts; its relationship with the load limiter force can be expressed by the standard equation for flexible belt friction,

$$\frac{T_c}{T_L} = e^{\mu\beta} \tag{51}$$

where T_C = tension load in the restraint device

T_L = tension load in the tube-ball unit

e = 2.718 (based on natural logarithms)

μ = coefficient of friction between cable and tiedown rail plate

β = angle of contact between cable and its mating parts

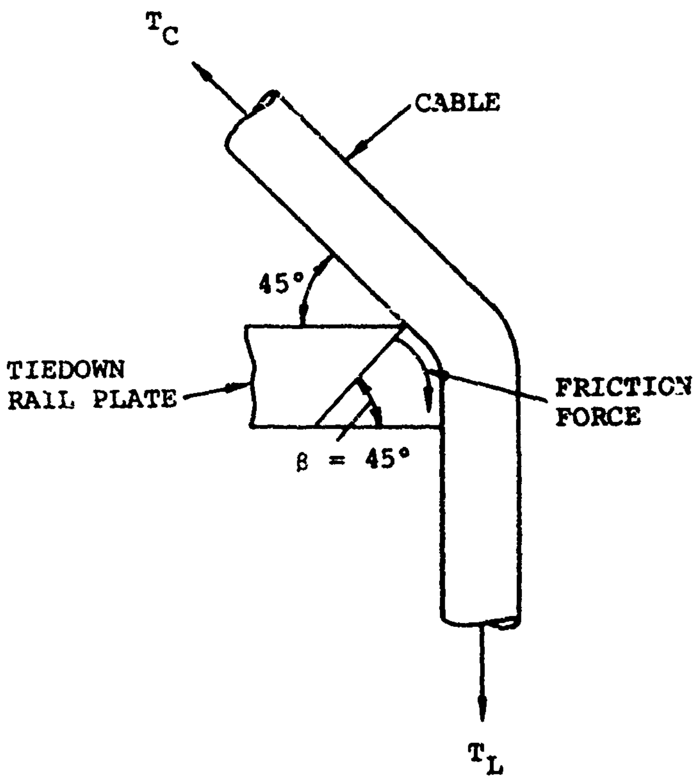

Figure 164. Friction Force Between Cable and Tiedown Rail Plate.

For design purposes, the maximum angle of contact is assumed to be 45 degrees (see Figure 153); therefore, the coefficient of friction magnitude must be designed to a relatively low value of 0.10, or less. For example, with β of 45 degrees and μ of 0.10, then, $e^{\mu\beta}$ equals 1.08. This means that the load developed in the tiedown will be 8 percent greater than in the tube-ball unit, prior to deforming. Consequently, a 7.5K load limiter level will result in 600 pounds of additional force to the cargo (or a total of 8,100 pounds).

When stroking occurs, the coefficient of static friction reduces to a relatively smaller value (referred to as the coefficient of kinetic, or moving, friction); this reduced friction force will then have small effect on the restraint system.

To prevent wear during normal flight operations, it is necessary to coat the cable portion of the unit. Selection of the coating material will be based on the use of a material with a desirable coefficient of friction, such as Teflon. Design verification will be accomplished during the development stage.

8.4 FUTURE AIRCRAFT DESIGN

The adaptation of the tube-ball load attenuator kit to new aircraft can be accomplished in several ways:

1. Design the cargo load supporting structure for installation with a standard-design load attenuator kit. The integral package will have the means of selecting the desired tube-ball load level.
2. Design the load limiter installation structure to fit the new aircraft structure. This method leaves the structural installation concept for the designer.
3. Build the load attenuator as an integral part of aircraft cargo supporting structure, easily accessible for replacement. For example, the floor frame structure at the tiedown location could be shaped to the tube configuration of the tube-ball concept. This technique would require that the tube structure be capable of reacting to both the dynamic and static load levels.

An alternate to the tube-ball load limiter kit would be to design the same cargo supporting structure as the load attenuator. For example, the floor frame, when deformed during dynamic crash conditions, would result in a relatively constant cargo load level. This is accomplished by loading the frame material in its plastic or yielding range. Therefore,

during normal flight conditions, the same structure must be capable of resisting static loads pertinent to the elastic range of the material. This correlation between the dynamic and static load values is complex in nature and requires a detailed study.

Another concept requires designing the structural material of the outer or fuselage shell to deform permanently upon impact without failing completely. When transmitted to the cargo floor structure, the impact loads will result in relatively lower crash pulse magnitudes than are presently realized. A unique design could result in the use of web-type tiedown devices as the only required means of restraint.

The load attenuator intensity selection will depend on such aircraft design requirements as flight performance and internal cargo capacity. The highest practical intensity value should be chosen to minimize the use of cargo tiedown devices and to obtain maximum crash survivability levels.

9. CONCLUSIONS

Initial conclusions drawn from a review of cargo restraint technology and an analysis of the CH-47 helicopter airframe are that:

- Existing static design philosophy is not compatible with proposed dynamic crash restraint criteria.
- The existing CH-47 airframe, including floor and floor frames, is not feasible as the cargo load supporting structure for proposed maximum survivability dynamic crash restraint criteria.
- Use of existing Army nylon tiedown devices is not feasible because of the large number of nylon devices required for dynamic restraint. (Tiedown chains were eliminated because they are not compatible with dynamic restraint criteria. MB-1 chains should not be used for airborne cargo restraint.)
- Current accident investigation coverage of secondary cargo-related effects (which contribute to human injuries and fatalities) is inadequate. A more detailed reporting procedure is required.

Based on proposed design criteria and a comparison of candidate cargo restraint systems, it is concluded that:

- A system of energy-absorbing (or load-limiting) devices with low-elastic tiedown straps will greatly improve cargo restraint effectiveness and will afford better protection to the crew. (See Figure 1.)
- Of the candidate energy absorbers evaluated, the tube-ball load-limiter device offers the most advantages. As proposed, it will add an insignificant amount of weight to the helicopter (weight empty) and can be developed, tested, and installed at little expense.
- The recommended system, proposed as a retrofit kit, incorporates 7.5K tube-ball load-limiter devices with an 8-inch stroke capability as an integral part of the CH-47 helicopter structure. (Although the tube-ball device may be applied as either an add-on or integral component, the integral application is preferred because the add-on units would be subject to added hazards of exposure.) In addition, low-elastic tiedown straps are to replace existing nylon devices and chains.

- Development and testing of the proposed 7.5K restraint system should be undertaken. Testing should include sled or helicopter crash tests under conditions simulating actual dynamic crash impulses.

- A lightweight, compact, inextensible cargo net is required to restrain loose cargo and equipment and thereby promote crash-safety. Provisions for storage of restraint and maintenance equipment are needed in present and future aircraft to prevent injury to personnel.

An evaluation of the 7.5K load-limiter restraint system against the existing Army nylon tiedown system indicates the following advantages for the proposed system:

- A 50-percent increase in load-carrying capacity, along with a substantial increase in energy absorption capability; an ability to restrain heavier items of cargo.
- A reduction in the number of restraint devices required, shortening the time to rig and derig cargo.
- Greater overall mission capability and aircraft performance due to improved internal payload effectiveness and operational cargo-handling times.
- Significantly higher percentile levels of survivability during combat operations (see Figure 2) where a minimum number of tiedown devices are employed. Comparable improvements in survivability will be achieved in administrative missions if correct restraint practices are employed.

Since cargo handling personnel do not now think in terms of flight safety, a crash-safety educational program is needed. Further improvements in crash survivability and reductions in potential fatalities are expected to result if correct tiedown procedures are stressed and practiced in field training. A uniform tiedown procedure for combat operations is also required to provide maximum survivability with a minimum number of restraint devices.

The preliminary design of the selected system meets all study objectives and should be implemented; furthermore, this concept should be applied to all operational aircraft. Future aircraft structures should be designed for dynamic crash conditions on a common basis with flight design envelopes to allow the airframe to absorb a major portion of the impact energy, thereby reducing the need for restraint systems which require separately packaged energy absorbers. The highest capacity load-attenuating systems should be incorporated to achieve full survivability levels with a minimum number of tiedowns.

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APPENDIX I
DESCRIPTION OF INTERNAL CARGO HANDLING IN VIETNAM

Under actual combat conditions, internal cargo (if secured at all) is generally secured with only token tiedowns. Combat crew philosophy is "Why waste time to tie down cargo before you take off, if the VC are going to shoot and kill you while you are doing it?" (Statement reported in Boeing Field Service Report.)

When the pilot sees that the load is on board, he takes off! Consequently, when ground exposure is minimized in a hostile environment, internal cargo loading and restraint time is reduced. In addition, combat crews consider the ability to rapidly jettison cargo (in the event of an imminent forced landing) to be more important than full cargo restraint against the effects of shifting cargo, from the viewpoint of time involved.

Generally, vehicles are tied down with "available" MB-1 chains, but this is done intuitively; the crew does not follow the -10 Handbook or any other flight-safety rules or criteria. See Figures 165, 166, and 167.

RVN personnel (crew and passengers) are not unaware of flight safety, as indicated by the precautions they take in the event of flash fires (they cover exposed parts of their bodies; i.e., arms, hands, etc.). This appears to be standard procedure for the crew, and may indicate results of training on imperative factors. It also may indicate a corresponding unawareness that cargo tiedown is a crash-safety imperative.

Apparently, little thought is given to injuries or fatalities that may result from cargo or tool boxes flying around in the event of a crash. Cargo nets are not usually used for small, miscellaneous cargo; and nets of this type are not normally carried with the aircraft. These conditions are illustrated in Figures 168 through 171.

Training for Cargo Tiedown

Helicopter flight crew training in cargo handling, loading, etc., is given at Fort Eustis, Virginia, and Fort Bragg, North Carolina. Some Army personnel have been given proper training in cargo tiedown procedures. However, as RVN crew members are rotated back to the United States (or become casualties), a foot soldier may be promoted through ranks to gunner and crew chief or loadmaster, without formal training in the proper

Figure 165. Installation of MB-1 Tiedown Chains in r CH-47.

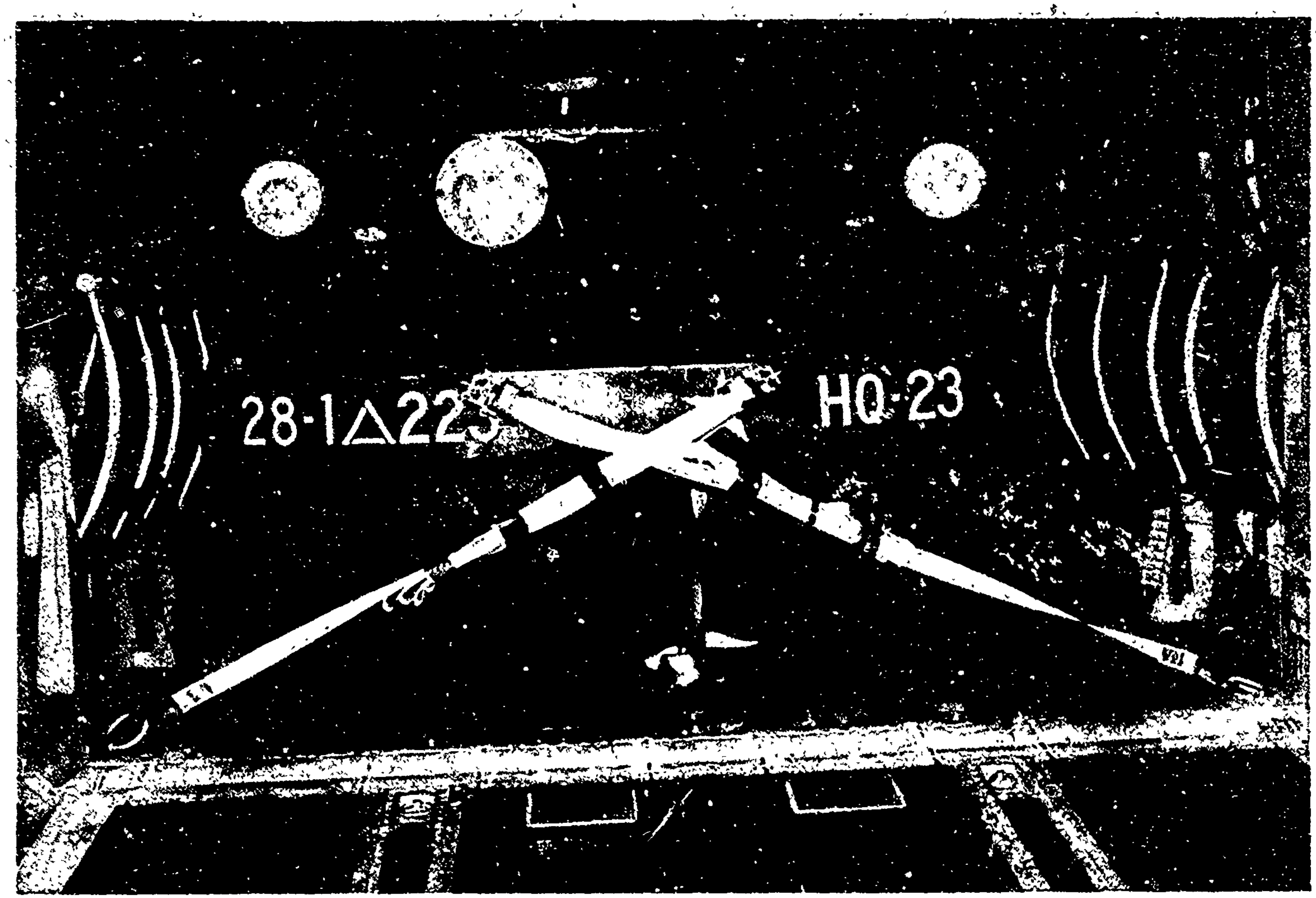


Figure 166. Typical "Token" Tiedown of Truck.

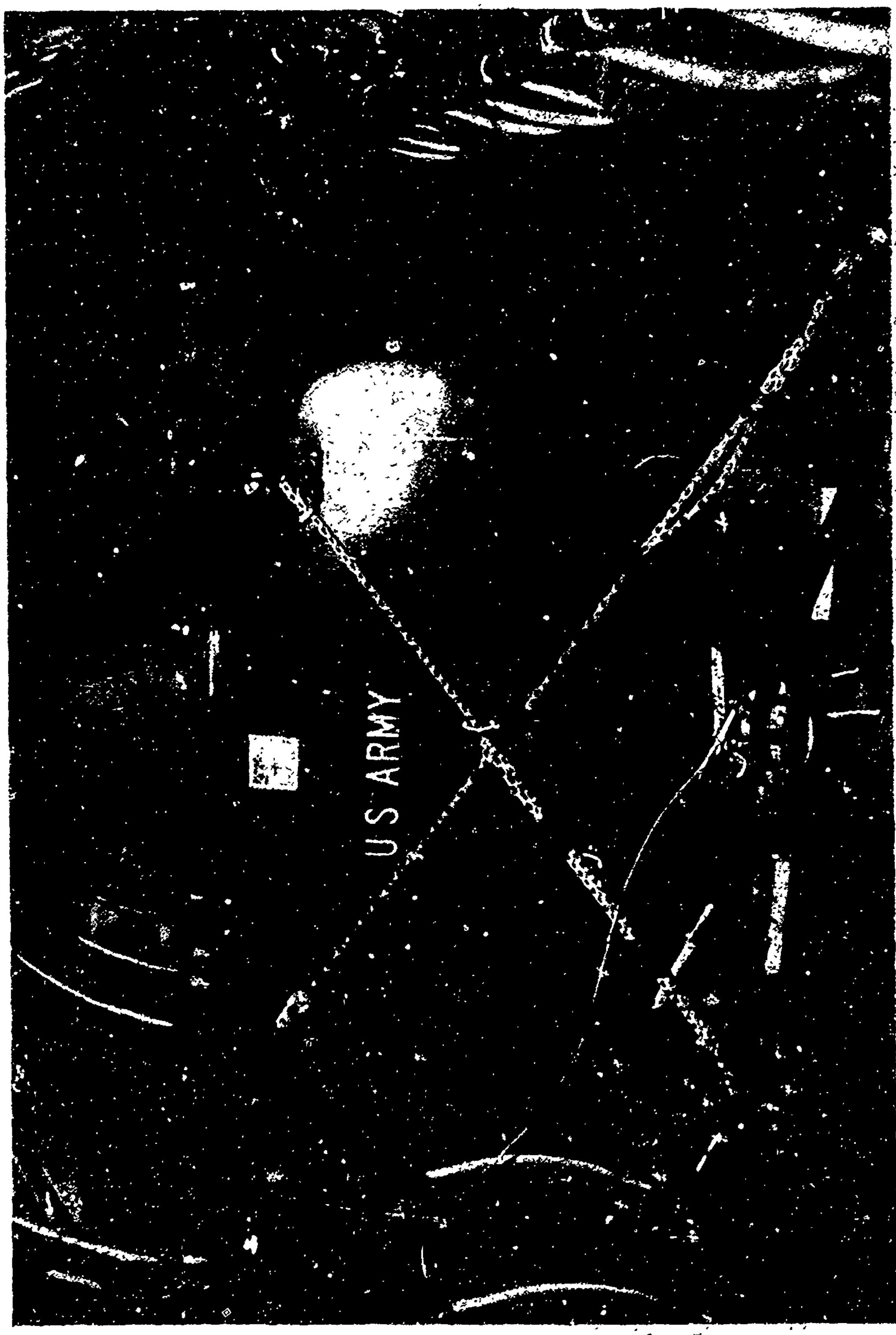


Figure 167. Typical Tiedown of Extended Range Fuel Tank (Conus Photo).

Figure 168. Interior of CH-46 Showing Gunner Sitting on Water Can, and Other Loose Equipment.

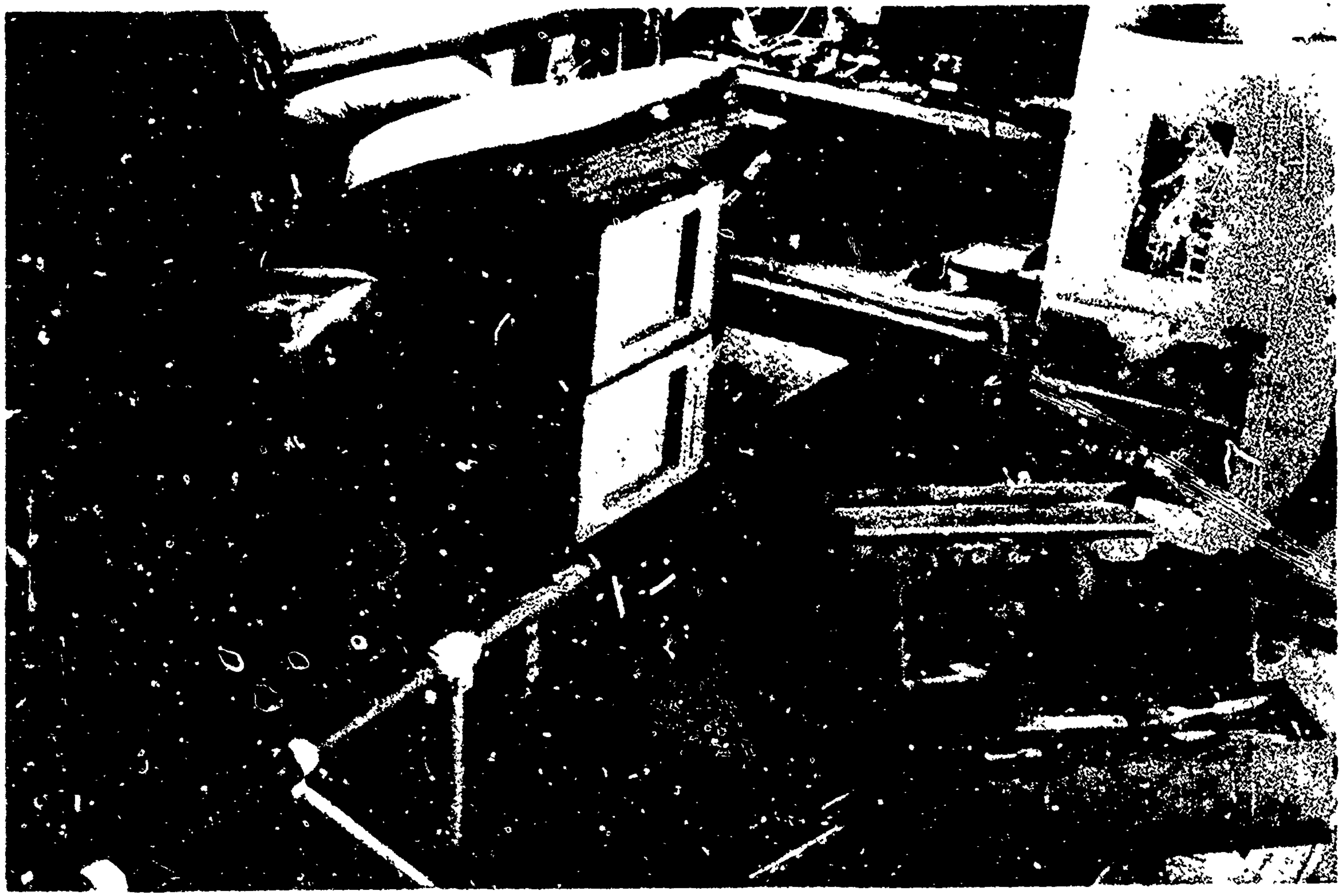


Figure 169. Interior of CH-47 Showing Improvised Gunner's Seat, Tool Boxes, and Miscellaneous Gear, all Unrestrained.

Figure 170. Improvised Stowage of Hydraulic Fluid Between RH Station 440 and 486 in a CH-47 (RVN Photo).

Figure 171. Water Can Tiedown in a CH-47 (RVN Photo).

methods of internal cargo restraint. Whatever knowledge he may obtain comes from his buddies or the man he is replacing; therefore, basic classroom-type training is much diluted.

Boeing field representatives have been conducting on-the-job training (when possible), but workload and combat environment relegate this activity to a low priority (as evidenced in Field Service Reports coming back from Vietnam). Also, the relative ease and frequency with which most loads are handled externally results in diversion of responsibility to the ground crew and a lack of concern on the part of aircraft personnel.

From the observations of Boeing field service representatives, the flight-safety officers are not stressing proper cargo tiedown procedures under combat conditions.

New Aircraft Delivery Storage Space

When new aircraft are turned over to ferry crews, flyaway equipment has not been properly secured. New aircraft leave the plant with the flyaway equipment tied down with one or two pieces of clothesline. The -10 Handbook (Section 13-115) instructions on general cargo tiedown call for nets or a lattice of straps for proper security. The latter type tiedown takes considerable time to accomplish.

NOTE: The standard flyaway kit for the CH-47 aircraft is:

Kit	Weight (lb)
114E0002-1 (CFE)	326
114E002-2 (GFE)	234
Total Weight	560

NOTE: The -1 kit consists of engine nose covers, etc. The -2 flyaway kit consists of 8 MB-1 chain tiedowns (10K capacity each) and 32 CGU-1/B nylon straps (5K capacity each). These are the items (560 pounds of loose equipment) that are secured with clothesline on flyaway.

No cargo nets are included in the Chinook flyaway gear requirements. To be used, they must be requisitioned or otherwise acquired in the field.

Adequate storage space for equipment is not provided in the basic aircraft design. (See Figure 172.) Litters are an exception and are normally stored forward in the cabin for erection as shown in Figure 173.

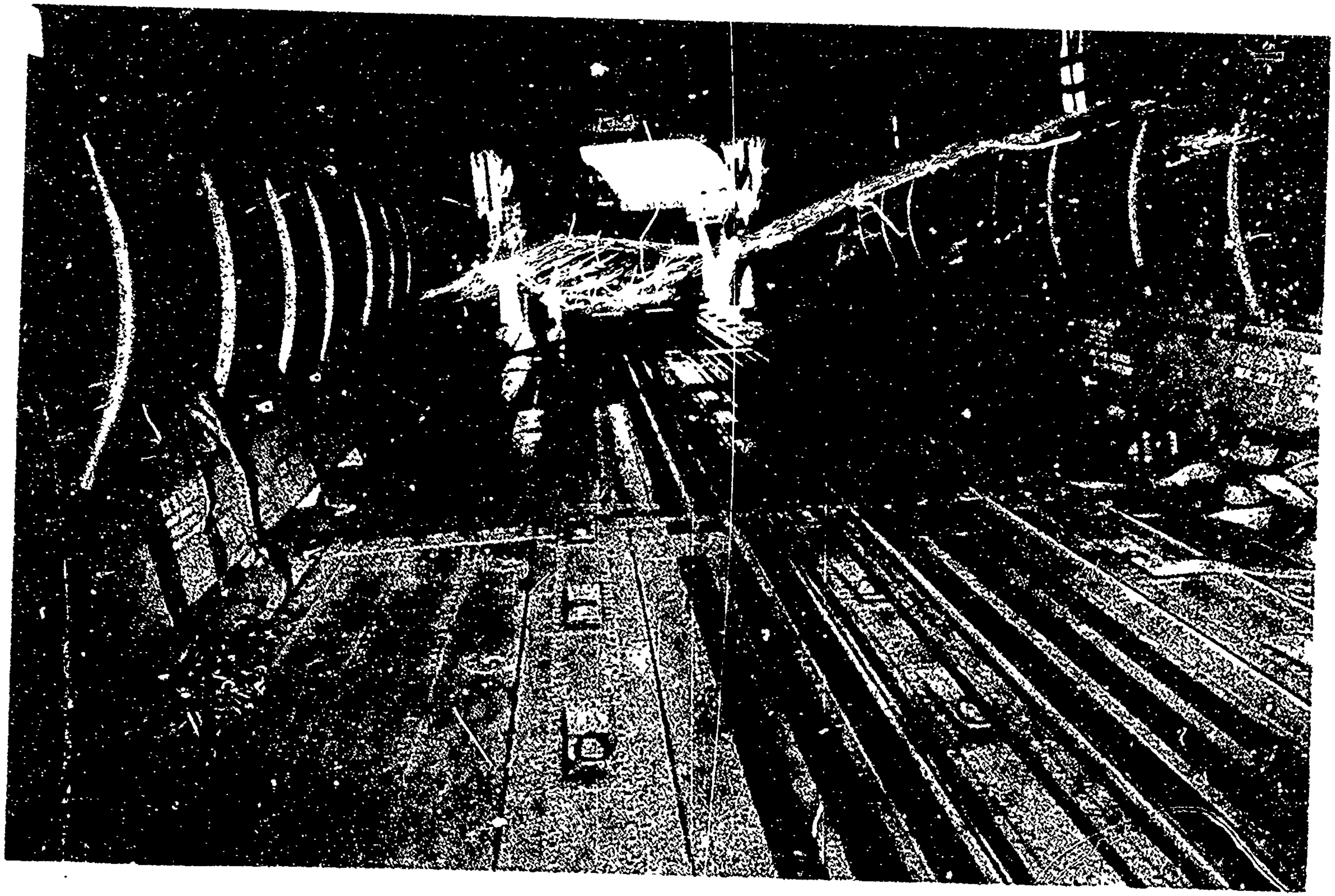


Figure 172. CH-47 Interior. Note Stowage of Chain Tiedowns at Lower Left and Nylon Strap Tiedowns at Right Center.

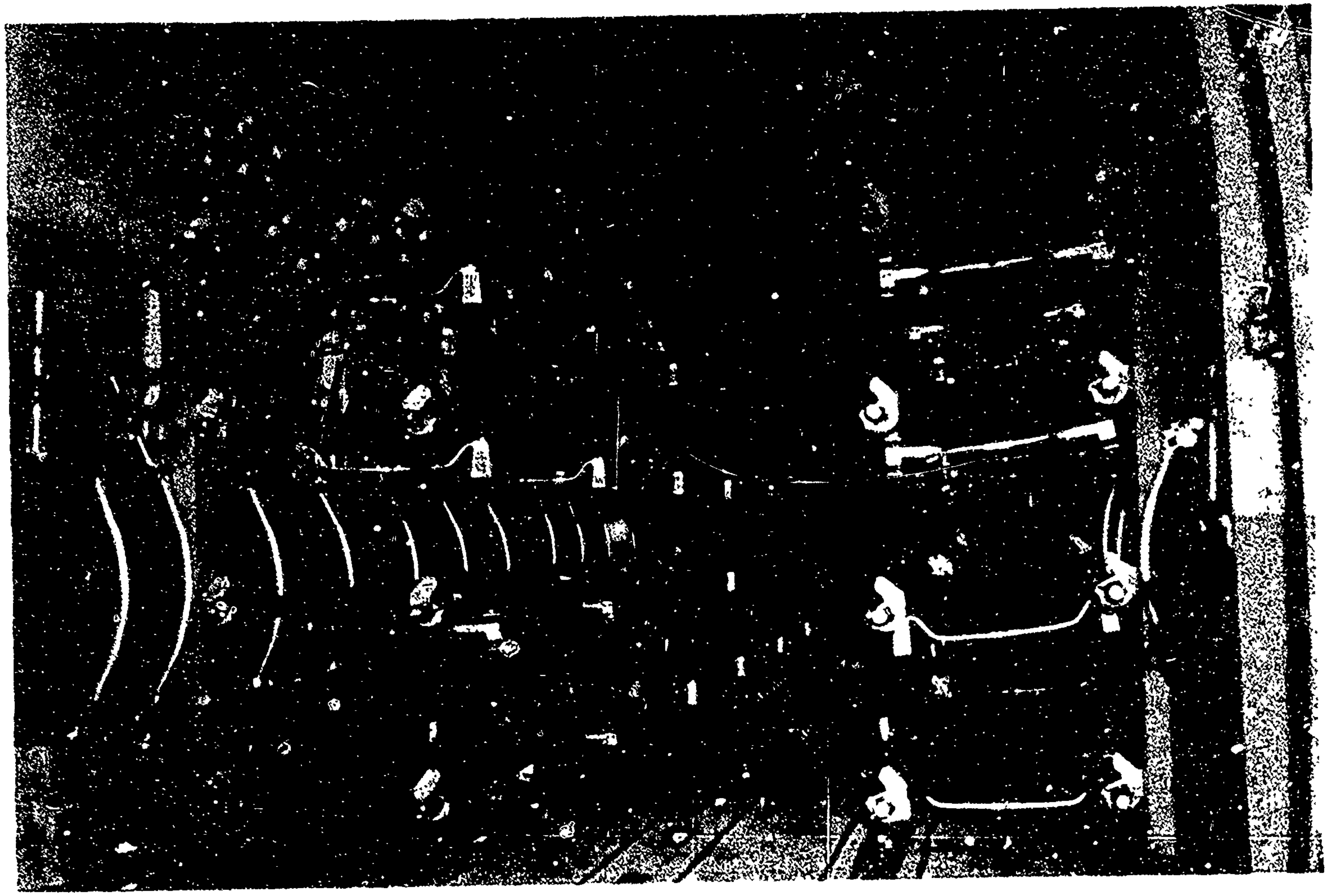


Figure 173. CH-47 Interior With Litters Erected.

In field operations, cans of oil are stuffed behind insulation, and tiedown straps and chain type tiedown devices are tied to the upper troop seat rails and/or stuffed behind troop seat back webbing. (See Figures 174 and 175.)

A swinging chain can be a very lethal weapon in the event of a crash landing. Also, there are times when tiedown equipment has been removed from the aircraft (due to lack of assigned storage space) for safekeeping and consequently is not on board when needed.

Other illustrations typical of the field environment which must be dealt with in cargo restraint are as follows:

Vietnam Environment	Figure 176
Tiedown Space Problems	Figures 177 through 180
Cargo Loading and Unloading	Figures 181, 182, and 183

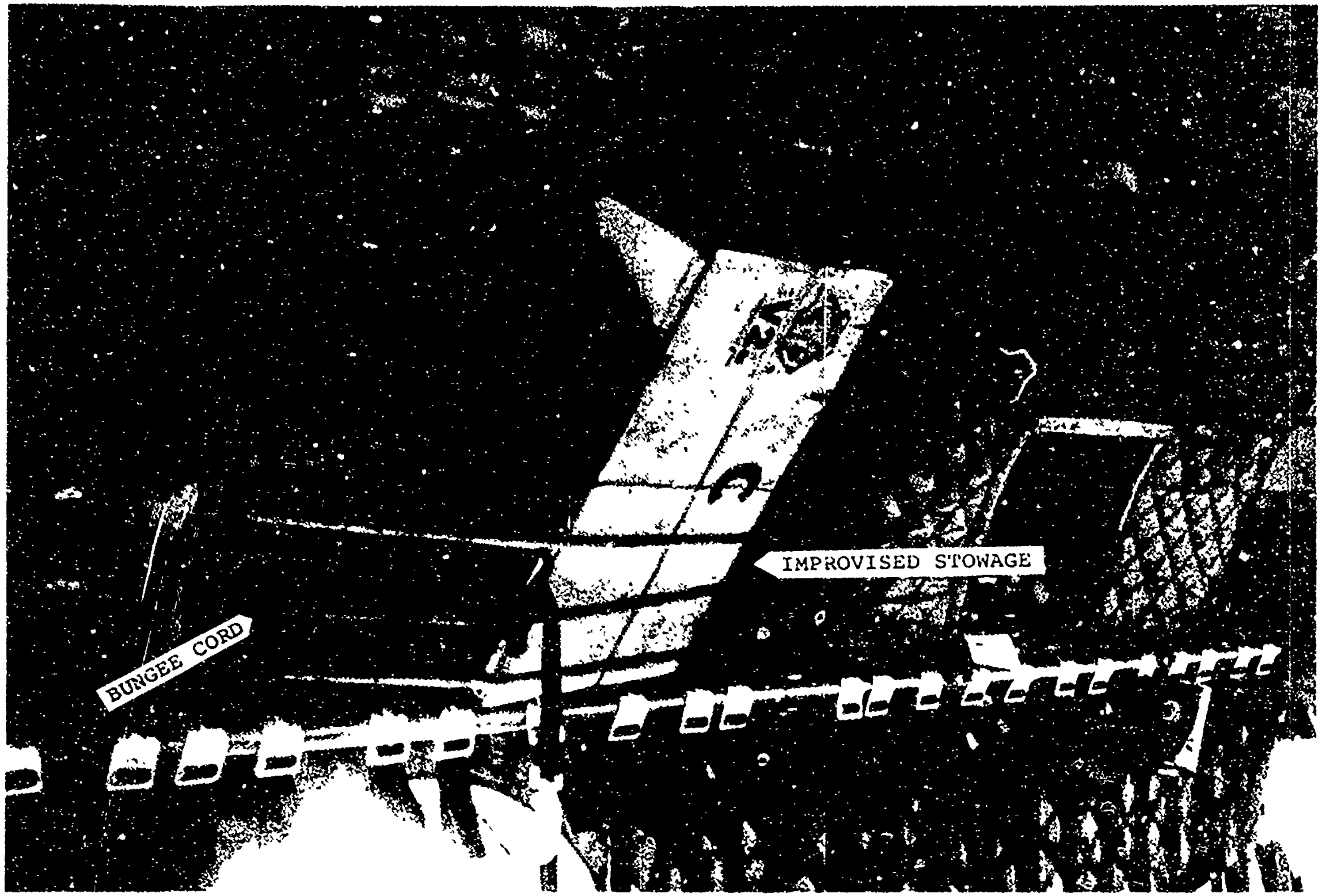


Figure 174. CH-47 Improvised Stowage (RVN Photo).

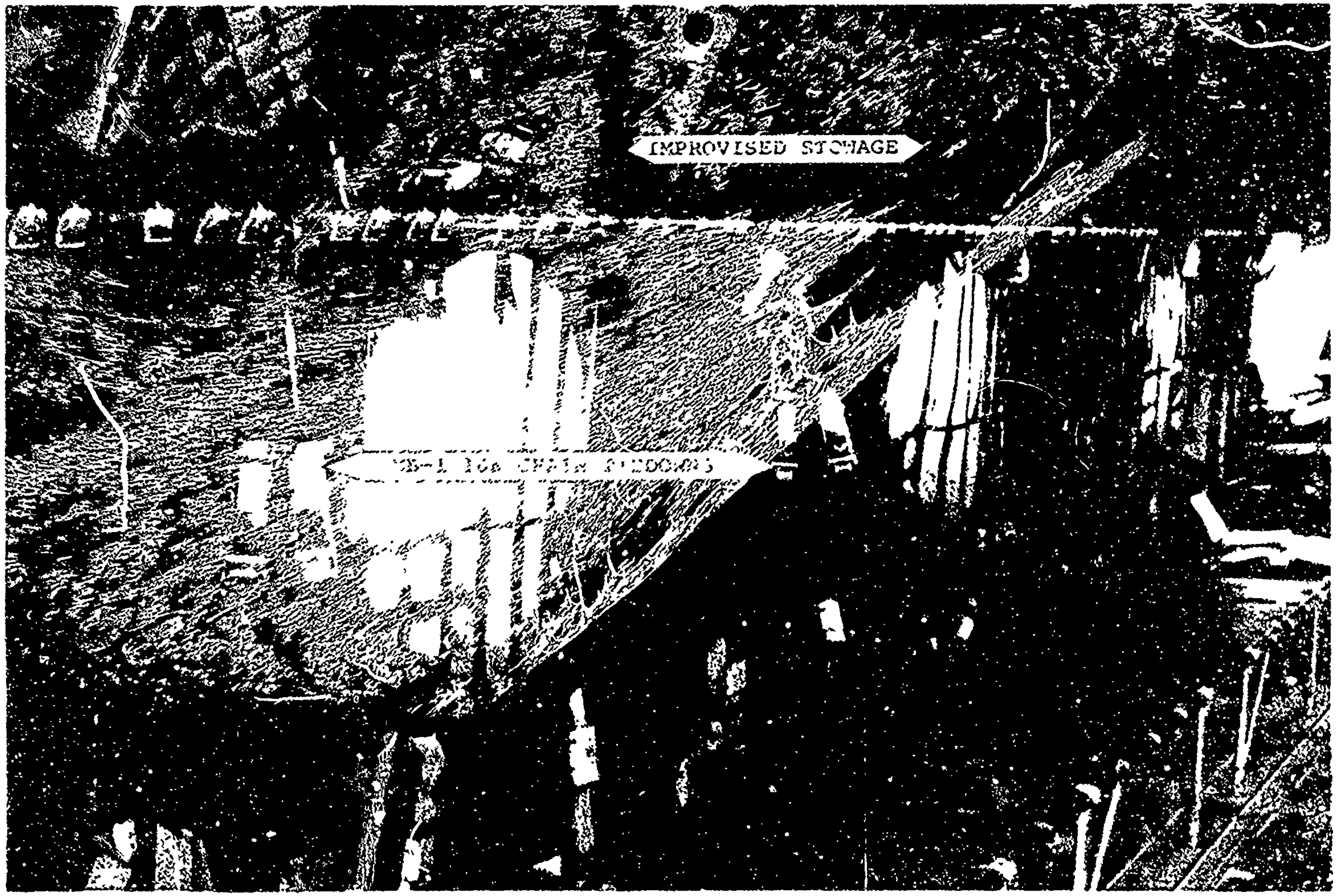


Figure 175. Improvised Field Stowage in a CH-47 (RVN Photo).

Figure 176. CH-47 Cargo Ramp With Floor Panels Removed to Show Dust and Dirt (RVN Photo).

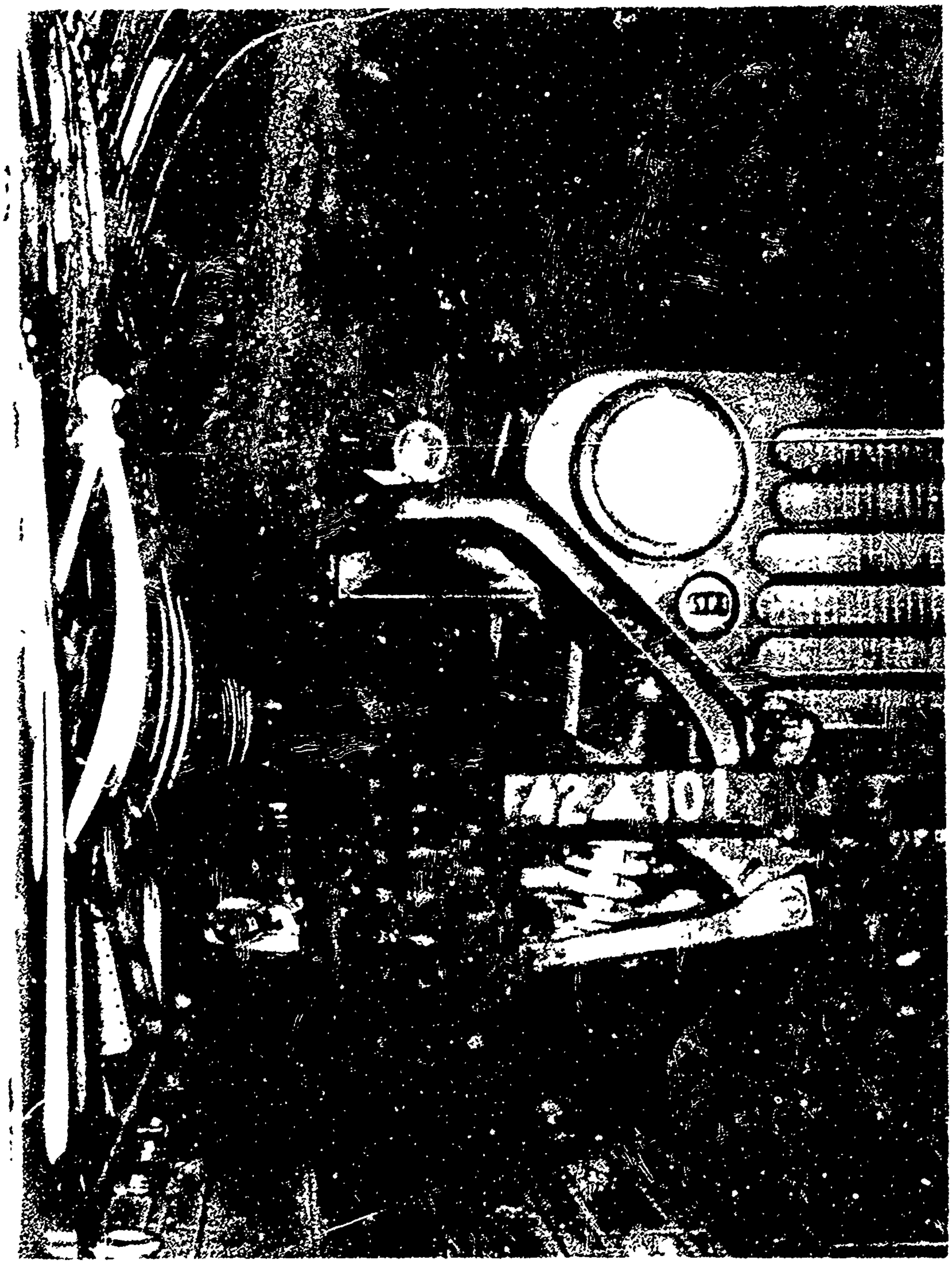


Figure 177. CH-47 Interior Showing Relative Truck to Cabin Clearance. Note Tie Down Lug on Truck Axle.

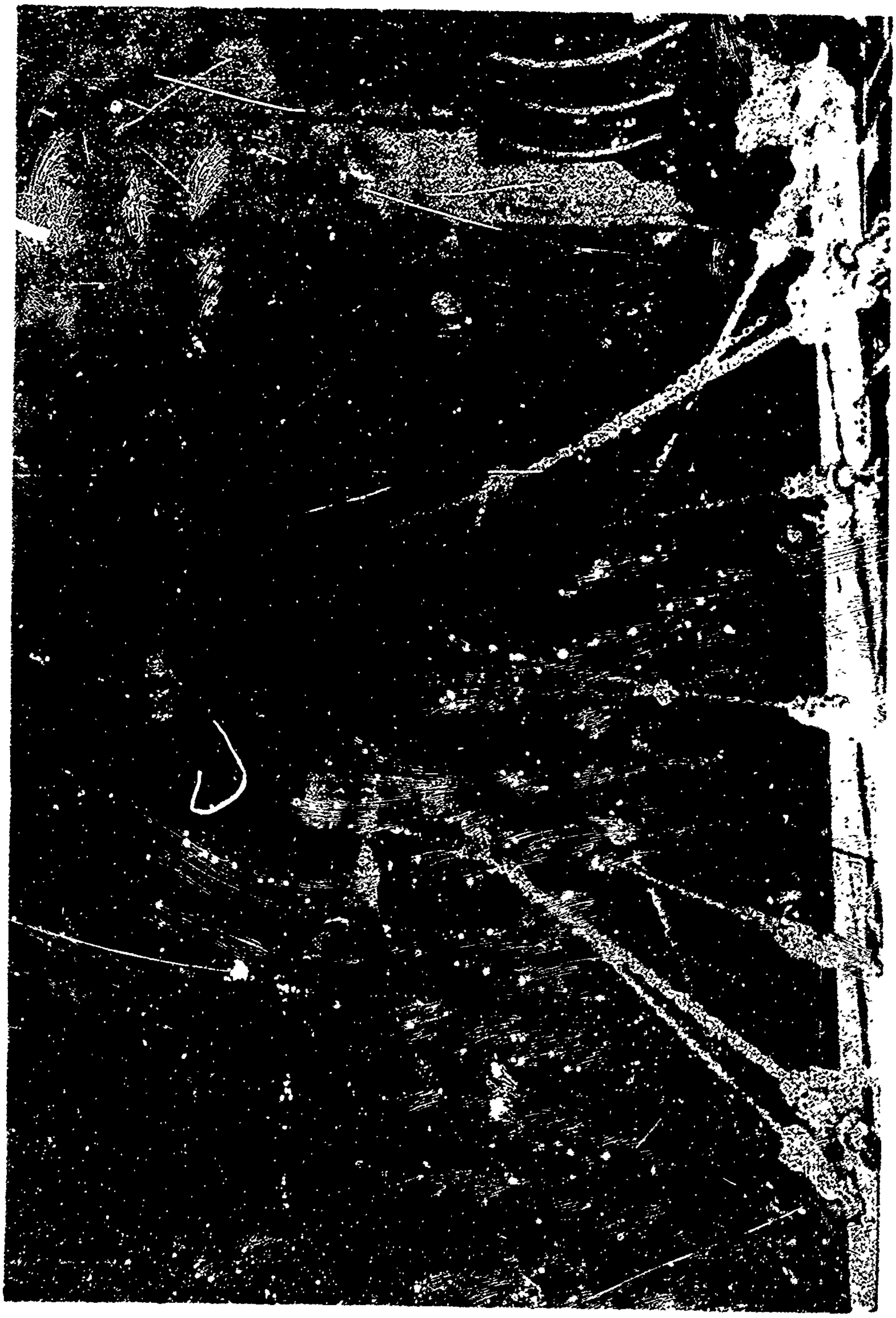


Figure 178. Typical Handbook Tiedown in C-130 Aircraft.

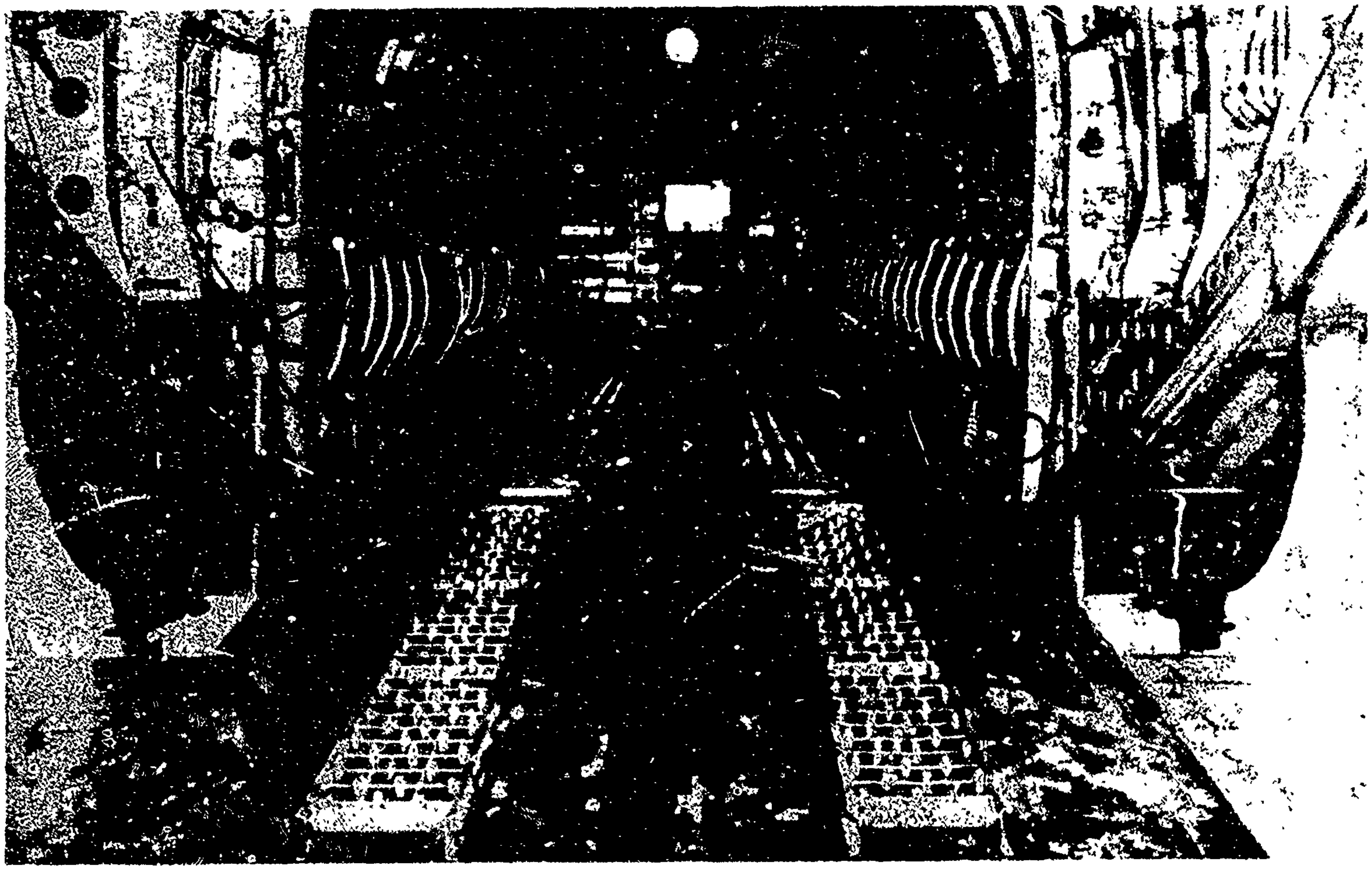


Figure 179. CH-47 Removable Roller Conveyors and Buffer Boards.

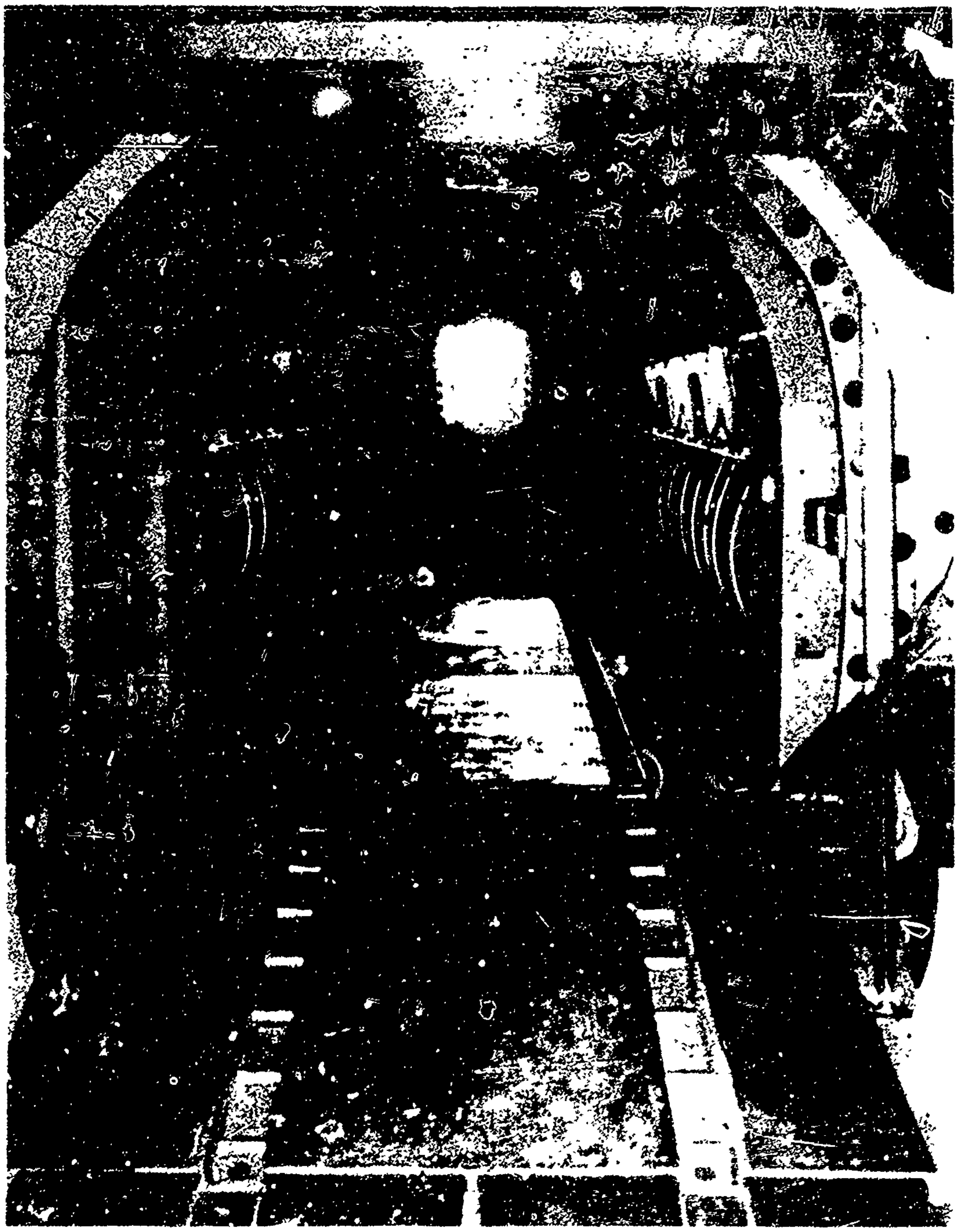


Figure 180. CH-46 Fixed Roller Conveyors.

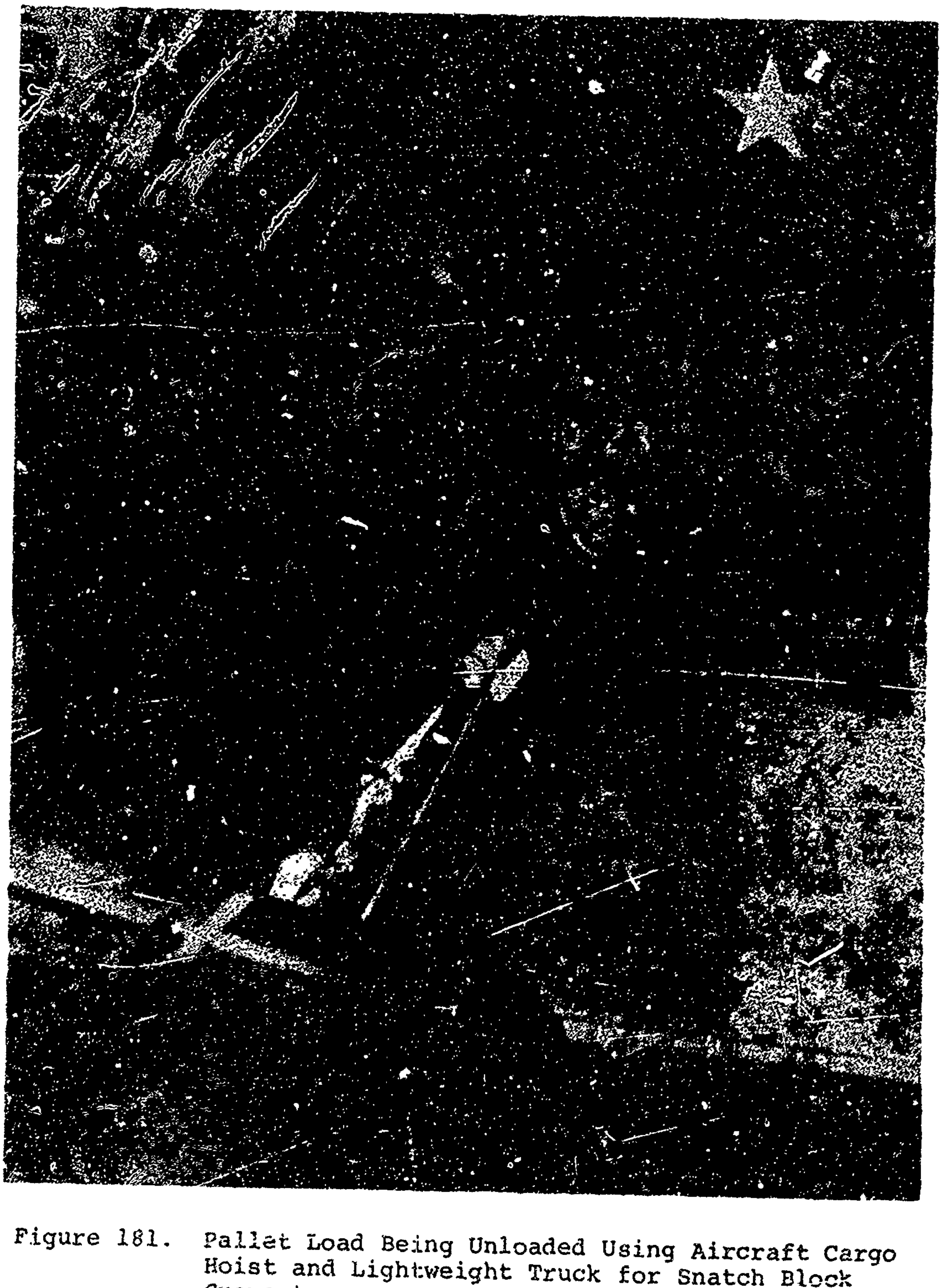


Figure 181. Pallet Load Being Unloaded Using Aircraft Cargo Hoist and Lightweight Truck for Snatch Block Support.

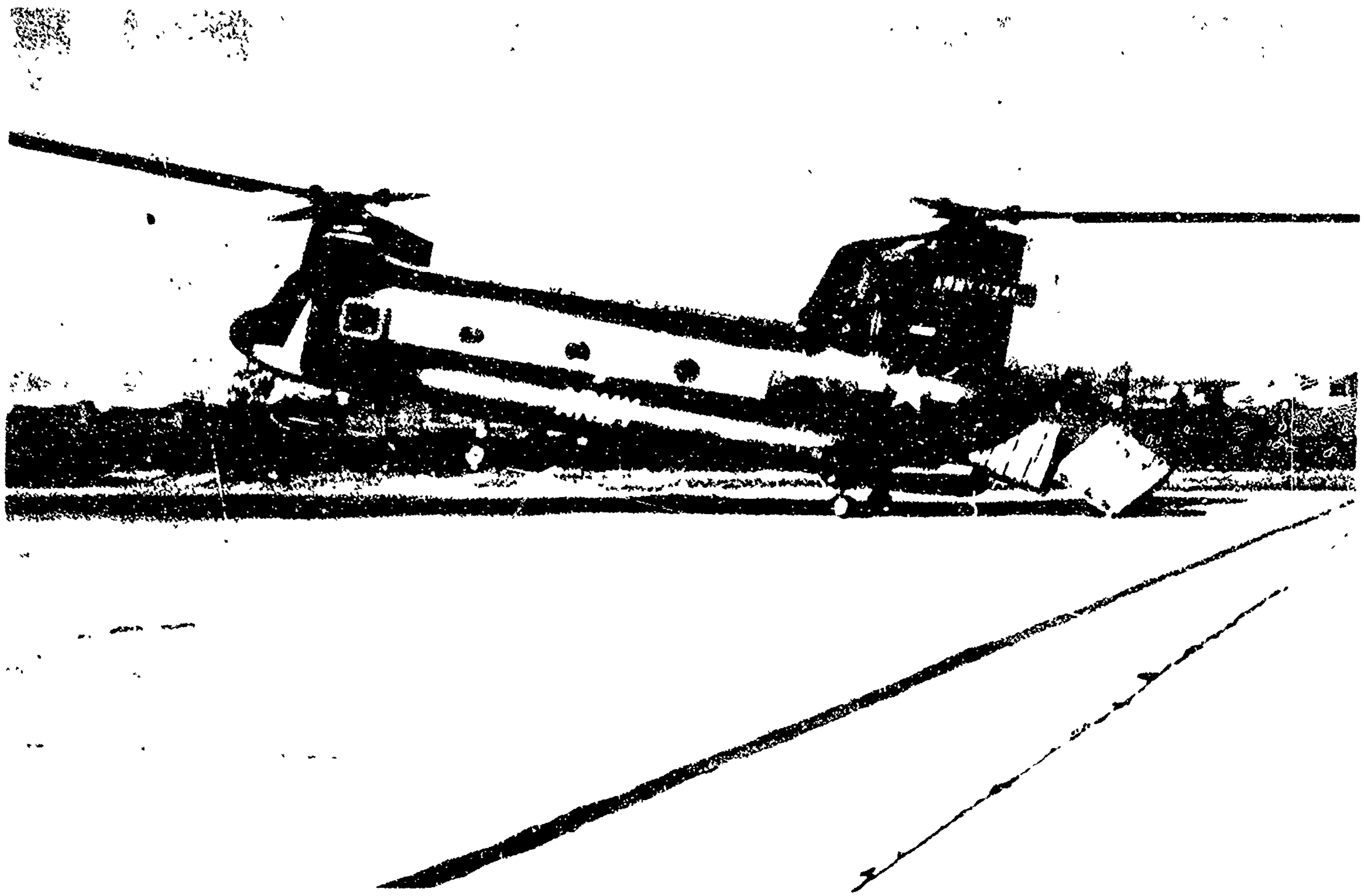


Figure 182. CH-47 "Dump Truck" Unloading of Pallets. Note First Pallet Load Breaking Up Because of Improper Security.

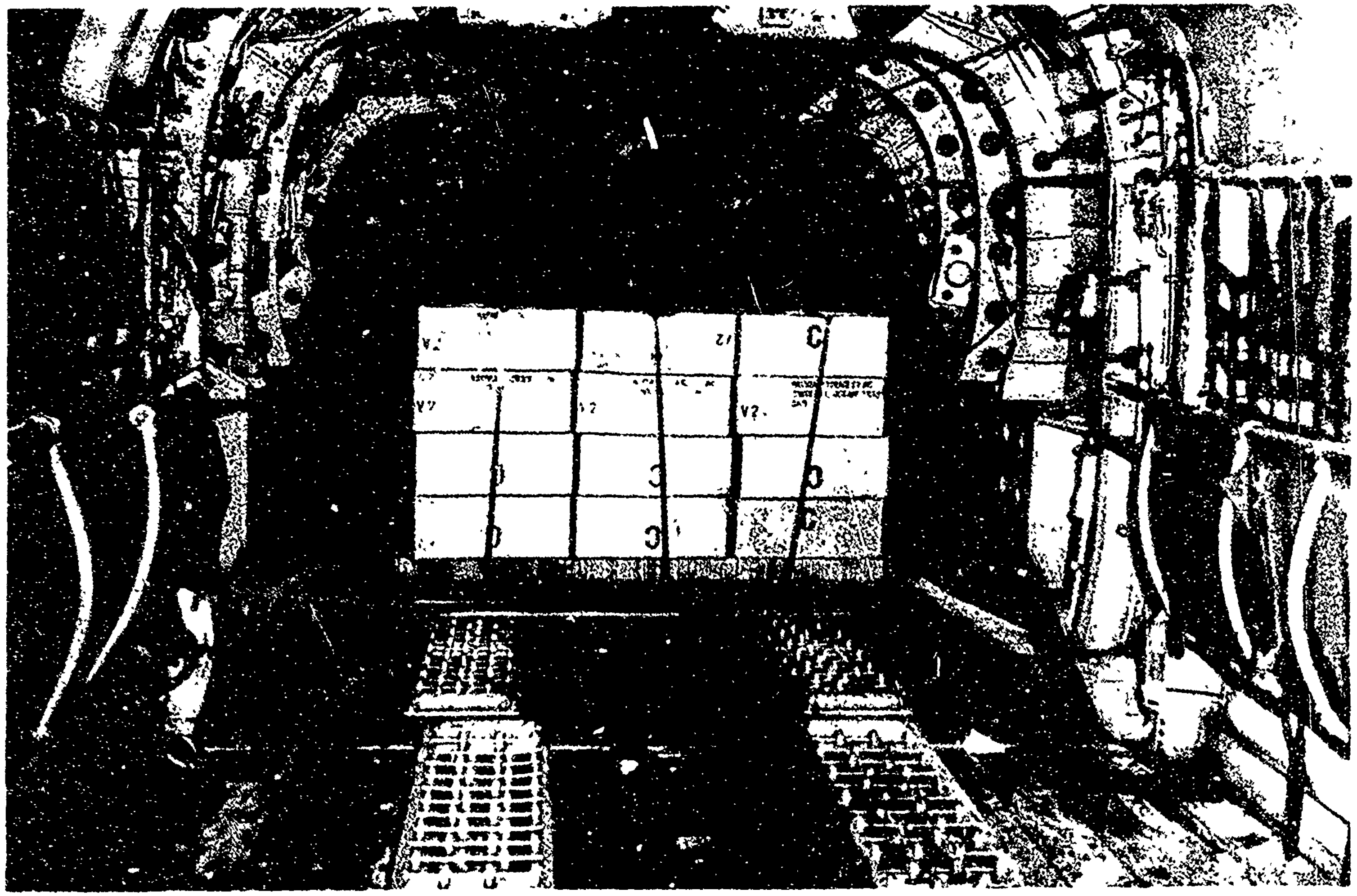


Figure 183. Interior View of CH-47 "Dump Truck" Unloading of Pallet, Using Roller Conveyors.

APPENDIX II

DESIGN CRITERIA FOR CARGO RESTRAINT SYSTEM SAFETY

The following design criteria are considered necessary for the development of a safe integral helicopter cargo restraint system:

1. The design shall be guided by the following fail-safe concept definition: "The stated condition that the restraint system can sustain misoperation by personnel, or partial or complete failure, without compromising the safety of the crew or passengers. Integral to the condition is the requirement for timely detection/warning of failure, and for timely repair of the failure."

2. The restraint system shall provide for retention of the cargo in all directions.

3. The restraint system shall avoid protuberances which may be hazardous to the crew and/or passengers.

4. The restraint system shall not impede egress of the crew or passengers during emergency conditions.

5. If load limiters are used to minimize cargo deceleration during a crash, the resulting cargo displacement shall not cause injury to the occupants or rupture of interfacing subsystem components such as fuel lines, hydraulic lines, or electrical wires.

6. The actuation load of any load limiter or other energy absorbing device used in the restraint system must not exceed the failure load of the tiedown ring or device to which it is attached.

7. Inextensible restraint devices should be selected so that "dynamic overshoot" properties are avoided.

8. If possible, low ductility materials should not be used in the restraint system-to-airframe attachments since these attachments must be capable of withstanding suddenly applied loads.

9. When not in use, the restraint system should be stored securely to prevent loose parts from striking occupants during a crash.

10. Handles and latches in the restraint system should be recessed or shielded to prevent accidental release of the cargo.

11. The connect and disconnect time for the restraint system should be minimized to facilitate quick and efficient operation under combat or emergency conditions.

12. A warning system should be devised which will alert crew members to an improper installation or connection in the restraint system.

Table XXXV presents data on helicopter accidents, including proven or possible causes. Where fatalities occurred, a determination is made as to whether the accident might have otherwise been survivable (i.e., at least one survivor).

TABLE XXXV. ACCIDENT DATA

Date	Aircraft Type	Aircraft Ser No.	Proven (or Suspect) Cause	Fatalities	Otherwise Survivable
8/15/61	UH-34D	148101	Crashed on a mountainside in Thailand. Steel strakes either broke or slid from under tiedown straps.	2 crushed	Yes
10/18/62	HSS-2	149004	Flew off a carrier and crashed under IFR conditions. The sonar dome is thought to have knocked operator's seat loose.	1 sonar operator	Yes
3/17/64	UH-34K	147185	Ammunition boxes are reported to have broken loose in this crash.	0	Yes
11/21/64	UH-34D	150234	Crashed in water and it is thought that a crewman was trapped and drowned under flour sacks.	1 crewman	Yes
5/4/66	CH-47A	64-13138	Crashed and burned while heavily loaded with troops and cargo. Cargo may have contributed.	All	Unknown
5/9/66	CH-47A	62-2121	Crashed and burned; gunner didn't get out and it is thought that he was hit by a loose tool box.	1 gunner	Yes

TABLE XXXV – Continued

Date	Aircraft Type	Aircraft Ser No.	Proven (or Suspect) Cause	Fatalities	Otherwise Survivable
5/30/66	CH-47	64-13156	Crashed trying to land on mountaintop. Poorly secured gasoline drums in cabin broke loose, ruptured, and exploded.	All	Unknown
8/8/66	ACH-47	64-13151	Ammo boxes on an armed Chinook broke loose during taxiing accident. (Locking pip-pins were not installed.)	0	Yes
5/13/67	CH-47	66-0088	Was downed by enemy gunfire while carrying troops and munitions. Cargo may have caused deaths.	All	Unknown
11/17/67	CH-47	64-19046	Five persons were trapped in burning CH-47 by bags of rice.	5 passengers	Yes
1/19/68	CH-47	66-0090	A canister of troop immobilization (cs) gas exploded on rear ramp. Cargo restraint was not a factor.	1	Yes
3/19/65	CH-47	59-3450	The aircraft descended from 800 feet and crashed uncontrolled in an open field after loss of an aft rotor blade. The aircraft was	3 crewmen	No

TABLE XXXV — Continued

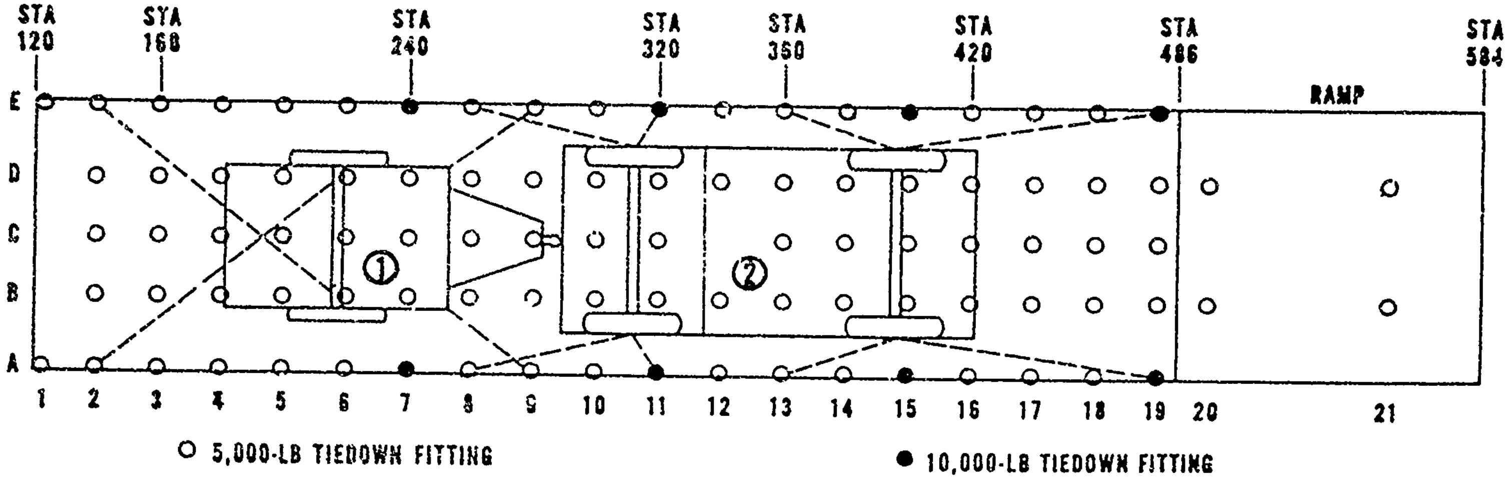
Date	Aircraft Type	Aircraft Ser No.	Proven (or Suspect) Cause	Fatalities	Otherwise Survivable
3/19/65 (Continued)	CH-47	59-3450	consumed by fire. All 3 crewmen died. (A simulated cargo of lead ballast secured per the -10 handbook. Its location in the ashes indicated that it had not shifted extensively.) Forward speed at impact was 35 to 60 knots.		
12/12/68	CH-47	66-0096	Aircraft heavily loaded (internally) with 6,000 lb of supplies and equipment, crew of 5 and 35 passengers. Unable to hover in two attempts. Load reduced. After takeoff, struck nearby wires; struck ground after climb attempt and loss of rotor speed. Struck radio antenna and guy wires after becoming airborne again. Aircraft crashed coming to rest on left side with nose partly submerged in water. Postcrash fire quickly extinguished. Internal load, insufficiently restrained, broke loose and shifted forward against forward cabin wall. Several passengers (children) were trapped. Two crewmen injured, one requiring evacuation.	5 passengers	Yes

APPENDIX III
TECHNICAL MANUAL DATA

U.S. Army instructions for tiedown of vehicles in a CH-47 using standard restraint equipment are specified in various technical manuals. Tiedowns are indicated to comply with AR 705-35. The following is a list of technical manuals, together with the vehicles to which they apply:

Technical Manual (TM)	Vehicles
TM 55-2320-218-10-3	A. M100 1/4-ton trailer B. M151 1/4-ton truck
TM 55-2300-201-10-1	A. M107 water trailer B. M37 truck
TM 55-2320-218-10-3	A. M151 1/4-ton truck B. M100 1/4-ton trailer with 500-pound load or M416 1/4-ton trailer with 500-pound load C. M151 1/4-ton truck
TM 55-2320-12-10-2	A. M101 3/4-ton trailer B. M37 3/4-ton truck
TM 55-2320-208-10-1	A. M170 1/4-ton ambulance
TM 55-1000-205-20-1	A. M38A1C 1/4-ton truck, with mounted 106mm recoilless rifle B. M151A1C 1/4-ton truck, with mounted 106mm recoilless rifle

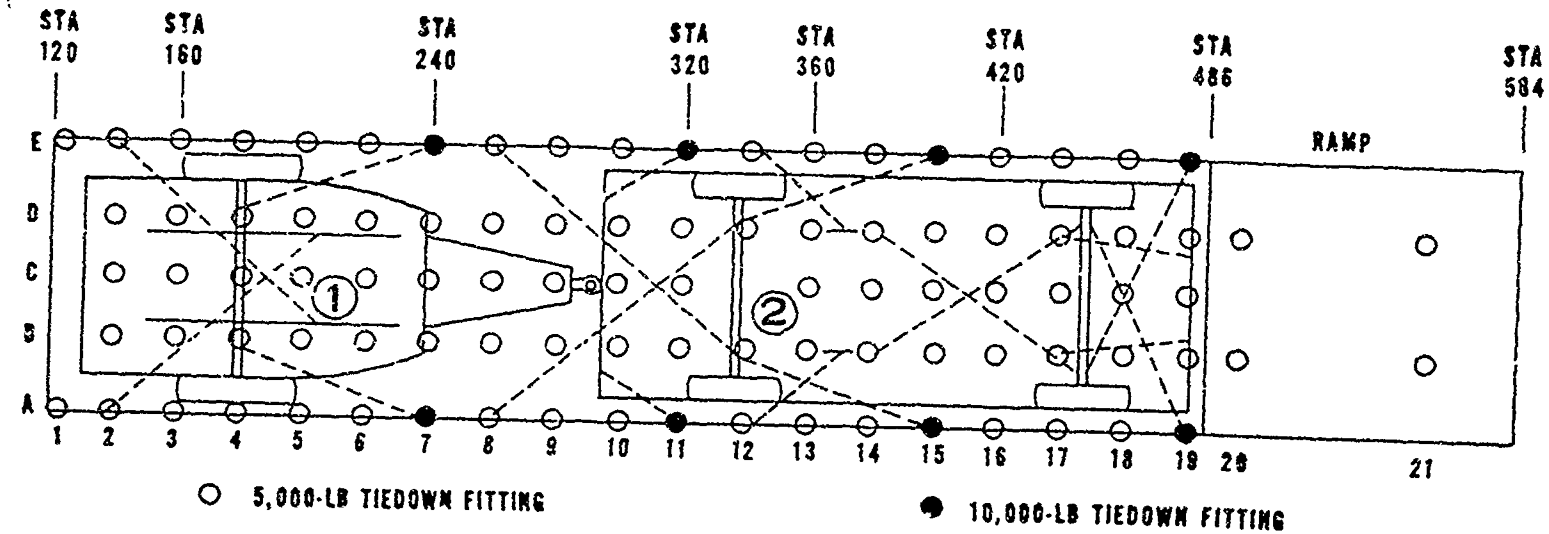
Figures 184 through 189 illustrate how the vehicles are positioned in a CH-47 for tiedown.



NOTE: FLOOR AREA BOUNDED BY ROWS 11 AND 13, AND COLUMN B AND D INCLOSE UTILITY HATCH.

Item	Description of item	Item facing	Location of reference point		Location of C.G	Approx. wt (lb)
			Reference point	Station		
1	M100 ¼-ton trailer	Aft	Axle	218	224	1,090
2	M151 ¼-ton truck	Aft	Front axle	401	364	2,360

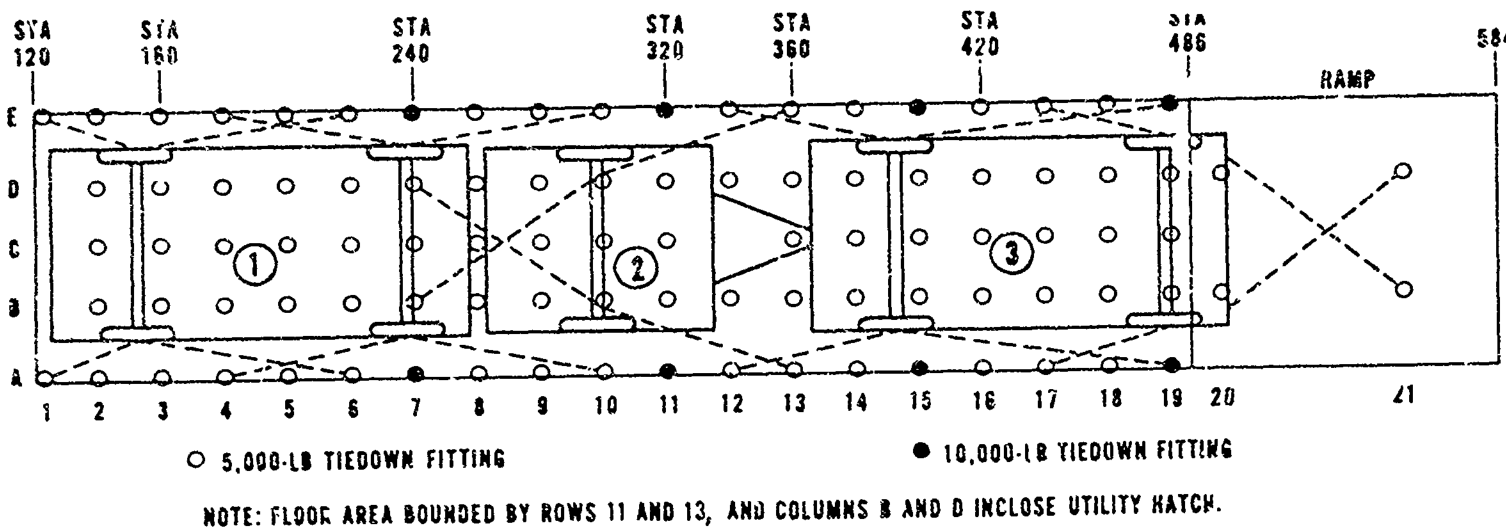
Figure 184. Loading Diagram for M151 1/4-Ton Truck and M100 1/4-Ton Trailer in CH-47 Helicopter.



NOTE: FLOOR AREA BOUNDED BY ROWS 11 AND 13, AND COLUMN B AND D INCLOSE UTILITY HATCH.

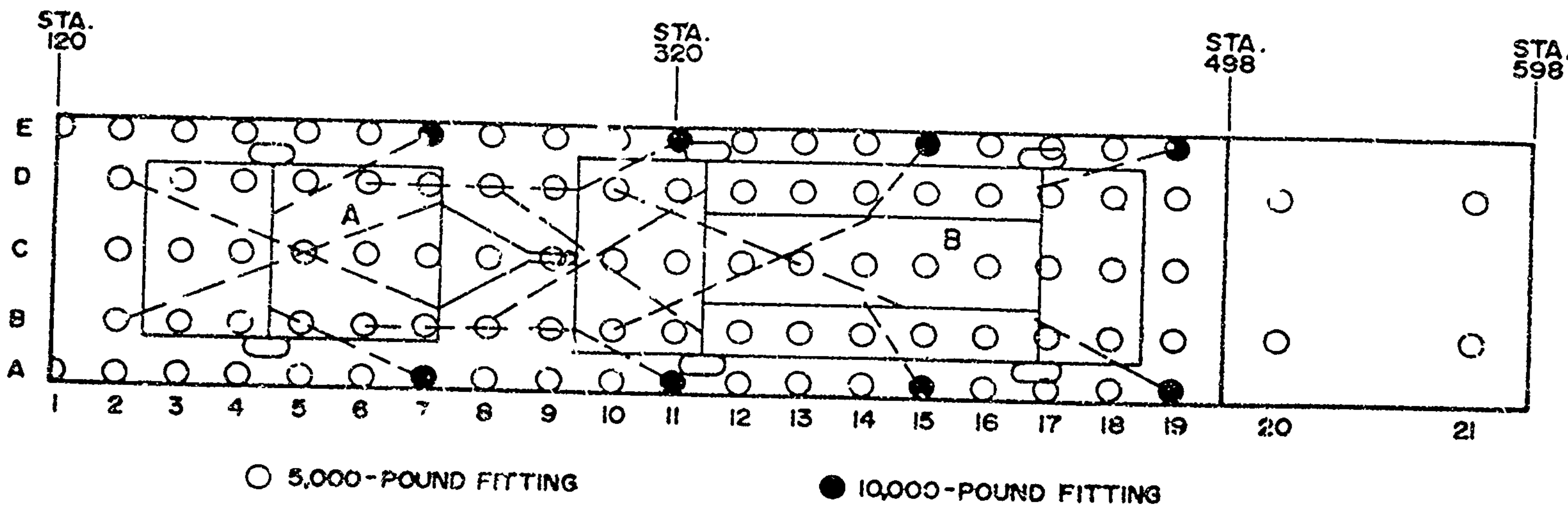
Item	Description of item	Item facing	Location of reference point: Reference point	Location of reference point: Station	Location of C.G.	Approx. wt (lb)
1	M107 water trailer	Aft	Axle	180	193	2,280
2	M37 truck	Aft	Rear axle	337	397	5,680

Figure 185. Loading Diagram for M37 3/4-Ton Truck and M107 1-1/2-Ton Water Trailer in CH-47 Helicopter.



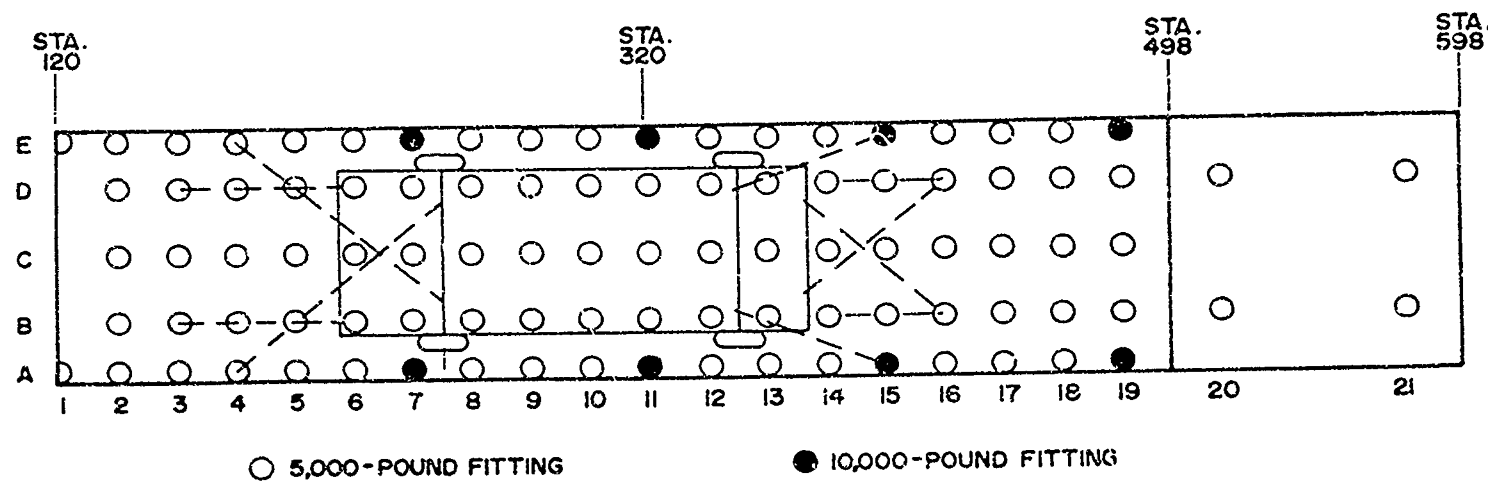
Item	Description of item	Item facing	Location of reference point		Location of C. G	Approx. wt (lb)
			Reference point	Station		
1	M151 ¼-ton truck	Aft	Front axle	238	201	2,350
2	M100 ¼-ton trailer with 500 lb load	Aft	Axle	298	304	1,090
	or					
	M416 ¼-ton trailer with 500 lb load	Aft	Axle	298	304	1,080
3	M151 ¼-ton truck	Aft	Front axle	478	441	2,350

Figure 186. Loading Diagram for Two M151 1/4-Ton Trucks and One 1/4-Ton Trailer in CH-47 Helicopter.



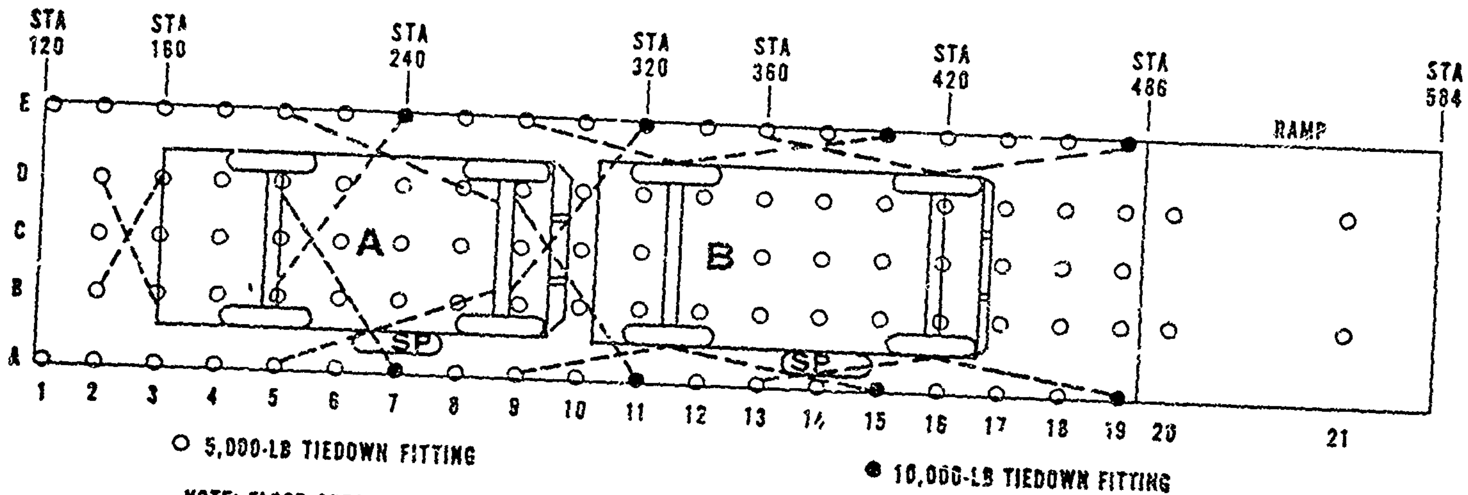
Item	Description of item	Item facing	Location of reference point: Reference point	Location of reference point: Station	Location of Center of gravity	Approximate weight (lb)
A	M101 ¾-ton trailer	Aft.	Axle	185		1340
B	M37 ¾-ton truck	Aft	Front axle	443	380	5687

Figure 187. Loading Diagram for M37 3/4-Ton Truck and M101 3/4-Ton Trailer in CH-47 Helicopter.



Description of item	Item facing	Location of reference point		Location of Center of Gravity	Approximate weight (lb)
		Reference point	Station		
M170 ¼ ton ambulance	Aft	Front axle	353	308	2,963

Figure 188. Loading Diagram for M170 1/4-Ton Ambulance in CH-47 Helicopter.



Item	Description of item	Item facing	Location of reference point		Location of C.G.	Approx. wt (lb)
			Reference point	Station		
A	M38A1C ¼-ton truck, with mounted 106-mm recoilless rifle.	Aft	Rear Axle	197	230	3, 220
B	M151A1C ¼-ton truck, with mounted 106-mm recoilless rifle.	Aft	Rear Axle	330	330	3, 235

Figure 189. Tiedown Diagram for M38A1C and M151A1C 1/4-Ton Trucks, With Mounted M106 Recoilless Rifles in CH-47 Helicopter.

APPENDIX IV
CARGO TIEDOWN TIME DATA

Basic time-study data for existing cargo restraint practice in accordance with technical manual requirements has not been found.

A search was made for organizational unit times for positioning, attachment tensioning, and releasing restraining devices. Possible sources of useful data included Forts Eustis, Bragg, Benning, Sill, and Rucker.

Some information, in the form of technical manuals, obtained from Fort Eustis (see Appendix III) included lumped times for load preparation, loading, restraint, and unloading.

Restraint times used in this study were based on information obtained from experienced personnel now acting as instructors at Fort Sill. A summary of this information and the qualifications used in formulating the estimates is given in the following excerpt from a report submitted by a Boeing field representative, Mr. Glenn Miller.

- -

BOEING/VERTOL FIELD SERVICE REPORT NO. 68-11MC-41

Title:	CH-47 Cargo Restraint Data Location
Location:	Ft. Sill, Oklahoma
Activity:	154th Aviation Co.

1. The writer has discussed the above subject with both Mr. Reichardt and Mr. Shefrin. It was pointed out that the precision which the memo implies is strictly theoretical. This statement is made due to the extreme variance in time to accomplish these diverse jobs between various crews and due to the various extent of pressure applied to them. For example, a crew here in the states might take a leisurely 6 minutes to tie down a jeep while the same crew in RVN may even close the ramp and go with the jeep not secured until in flight. Motivations vary to the extreme.

2. For the purpose of this report, the writer has interviewed several veteran flight engineers and crew chiefs from RVN that have about as much experience of cargo handling on a Chinook as anyone today. The problem was presented to them and their comments and estimates of average time to accomplish the various

problems are contained herein. Note that all figures presented here are estimates by people that the writer would consider as qualified experts in this field. Stop watch or "time study" data was not available.

3. In all of the time estimates that follow, the writer allowed the interviewed crew members the luxury of being assured that the chains and straps were properly pre-positioned (lying along the buffer boards) prior to starting the tiedown. The times do not include loading of the units or positioning them within the aircraft. The only considerations were that the only job remaining was to install the needed restraints. Then the only time considered for the removal of the restraints from the loads. No storing of the straps or chains and no time for off-loading the units is considered.

4. The time to install (attach) an MB-1 chain is from 15 to 20 seconds. The time to tension the chain then takes 15 seconds.

5. The time to attach a cargo strap is 5 to 10 seconds and less than 5 seconds to tension it.

6. The above will cause a variation in the time required to tie down a jeep. The crews were split about half and half in the use of either 4 chains or four straps for tying the jeep down. In each instance the jeep is secured in the same manner. The views in the -10 manual are followed quite closely in respect to the patterns of tiedown arrangement. Two chains are attached to the front bumper eyes, crossed and attached to 10,000# tiedown fittings. The aft restraints are attached to the bumperettes and crossed. The 10,000# fittings are used here also. The main variation is that some crews use the straps instead of the chains because they are faster and they feel that they are sufficient.

   Time to tie down a 1/4-ton jeep was estimated at 3 min. with the chains. Tiedown with straps would be correspondingly faster. Tiedown of the 1/4-ton trailer was estimated at 1 min. not hitched to the jeep. One strap is passed over the draw bar and holds it to the floor while the aft is restrained in the same manner as the aft of the jeep. With the trailer attached, the crews estimate the same increase in time (1 min.) due to the trailer slowing down the placement of the aft restraints of the jeep; in other words, to tie down a jeep with the trailer hitched up would take 4 min.

7. Time to tie down a 3/4-ton truck takes longer, as two additional chains are required. These are attached to the under carriage of the vehicle. No straps are ever used to restrain a 3/4. Only chains. Time is estimated to be 5 minutes to tie it down. Its trailer is estimated to take 1-1/2 minutes by itself and to tie down a 3/4 with the trailer hitched to it takes a total of 6-1/2 minutes for the same reasons as above.

8. Straps are the only restraints used to tie down a "mule". The time is estimated at 40 seconds. If the mule is fully loaded, the time may increase considerably if it is judged by the crew that the mule's load must be restrained also. This time will vary according to the conditions of the mule load. Generally, only two additional straps are applied. One restrains the load from shifting forward while the other stops it from shifting aft. These straps are attached to the aircraft tiedowns and not to the mule.

9. It takes 4 minutes to tie down an M-102 105mm howitzer.

10. P.O.L. drums have been excluded from internal loads in most Chinook units in RVN according to the crew's comments. Most are carried via sling since an accident caused such an extreme fire. However, while they were carrying them, the drums were arranged in groups of 10 drums each. It took 5 minutes to tie down each group. The pattern of tiedown followed the -10 manual.

11. Nobody, including the writer, is familiar with a "sealdbin" at this location.

12. A pallet of 155mm ammo contained 9 rds. and weighed 1100#. It took 5 min. to tie down each pallet. A pallet of 105mm ammo contained 30 rds. and weighed 1800#. They were arranged in 5 pallet loads. It would take 15 minutes to tie down the whole load. It can be seen by the above that there is a great advantage to hauling this type cargo by external slings. The sling loading is the most widely used in RVN.

13. The water trailer took the same type of tiedown as the 3/4-ton trailer and was treated in the same manner and took the same amount of time.

14. Surprisingly, when the subject of the rice bags was discussed, none of the crew members had ever restrained it. When captured rice was hauled, it was just stacked on the floor. The same was true for the distributed rice for friendlies.

15. Time to tie down a 40x48 pallet is estimated to take 2 minutes.

16. Time to release really started a controversy among the interviewed crews. Most of them contended that an on-the-ball crew would have most of the restraints off prior to touchdown in RVN with only one main aft strap to go. Generally, the crews would arrange their restraints so that the last aft one was a chain. Upon touchdown, a simple flip of the quick-release of the chain eliminated the last tiedown and the load was immediately started off. None could really honestly estimate an actual release time for a "casual" release of the load. Any time they hauled cargo in RVN they automatically assumed that they might come under fire at the delivery point. At other times, the off-loading of the cargo was so casual that no one paid any attention to the time of removal of the restraints. The restraints were simply taken off as they "got in the way".

17. The only document that the crews use at this location for internal cargo loading is the -10 manual. There are no unofficial documents involved, but training is carried on as handed-down techniques from crew to crew.

18. No nets are used on any internal loads as a matter of practice by any of the crew members interviewed.

19. One variation which proved interesting and which the writer was aware of but never really considered as extraordinary was the "short straps" used in the 1st Cav. These were the regular cargo straps cut to 8 ft. lengths to avoid the excess "tail" of a strap which is attached close to a load and makes its handling much faster and safer due to the absence of a "nest" of loose strapping. These straps were color coded red so that they could be selected quickly from the other straps in storage. 6 of these "shortys" were generally carried on each aircraft. The crews liked them very much.

- -

Cargo operations defined in the text as including loading, restraint, release and unloading are engineering estimates constructed from the Fort Eustis and Fort Sill information. Restraint times are tabulated in Section 7.

CARGO RESTRAINT DATA QUESTIONNAIRE

The restraint data questionnaire which was circulated to Boeing field representatives contained the following request for information.

- -

Information is needed regarding general Army state side (CONUS) internal cargo loading practices as follows:

1. Time to attach the MB-1 chain tiedown
   Time to tension the MB-1 chain tiedown

2. Time to attach the MC-1 or CGU-1A strap tiedown
   Time to tension the MC-1 or CGU-1A strap tiedown

3. Time to tie down typical RVN loads such as:

   1/4-ton M151 truck
   3/4-ton truck
   1/4-ton trailer
   3/4-ton trailer
   1/2-ton light weapons carrier (Mule)
   M102 (105MM) howitzer
   P.O.L. drums (55 gal.)
   Sealdbins (500 gal.)
   Specific sized loads of ammo
   Water tanks (trailers)
   Rice bags
   40" x 48" pallets

4. Time to release (remove restraint from) the above loads.

5. The number and type of tiedowns used for each item in #3 for proper restraint.

6. Field reps. stationed (or previously stationed) at Fort Sill, Fort Bragg, Fort Benning, or at New Cumberland Army Depot may know of official or unofficial documents used for training troops or load masters which contain any of above information which we could borrow for a short period of time.

7. Also, is the A-2 metal cable cargo net used - is it available to the troops for use? Are rope or nylon nets of any type used?

- -

APPENDIX V
COMMENT ON RVN OPERATIONS - ENGINEERING SURVEY

In August and September 1968, a review of internal and external cargo handling in RVN operations was made by a Boeing engineering survey team. The eye witness inspection trip covered the following helicopter companies:

Groups Visited	Mission	External/ Internal Cargo Ratio
205 ASHC	General Support III Corps	90/10
213 ASHC	Support 1st Division	90/10
242 ASHC	Support 25th Division	90/10
271 ASHC	General Support IV Corps	50/50
147 ASHC	General Support IV Corps	80/20
179 ASHC	General Support II Corps	90/10
196 ASHC	Support ROK forces	90/10
132 ASHC	Support Americal Division	80/20
178 ASHC	Support Americal Division	80/20
Co. A, 228th Avn Btn	1st Cavalry Division	75/25
Co. B, 228th Avn Btn	1st Cavalry Division	75/25
Co. C, 228th Avn Btn	1st Cavalry Division	75/25
Co. A, 159th Avn Btn	101st Division	90/10

Observations made during the inspection tour are summarized in the following paragraphs.

CARGO RESTRAINTS

1. Cargo restraints are rarely used. Most use is restricted to tiedown of vehicles, which are rarely carried internally.

2. Cargo loaded by hand, such as hot food, is never restrained.

3. Cargo of significant weight which must be pushed into the cabin is usually tied down in a token manner, perhaps with one strap longitudinally placed.

4. Lumber is a frequent internal cargo Usually it will be stacked on the floor, filling the aircraft to capacity. Tiedowns are limited to two straps laterally across the top. Lumber is usually standard 2x4 inches, about 16 feet long (see Figure 120).

PROTECTION FOR PERSONNEL

1. Seat belts are rarely used by crewmen in cabin.

2. Pilots will always wear restraint harness.

3. The CH-47 normally does not operate in "hot" landing zones. The only time this is allowed is when a tactical emergency exists and requires high level approval.

INTERNAL CARGO LOADS

Air Force conveyors, which are generally laid on the floor in arbitrary spacing without being tied down in any way, have been adapted for use in many Chinooks. Heavy cargo is fork lifted to the aft end of the ship and from there pushed in on the rollers by available manpower. One-half hour is considered normal loading time.

The Chinooks are constantly used to transport other items, in addition to cargo, between all points. The normal arrangement is that crew and passengers sit forward, and cargo or vehicles are loaded in the aft end. Forward seats are normally set up, while middle and aft seats are left folded. No one ever seems to bother with weight and balance, probably because the aircraft is usually not loaded to capacity.

One exceptional mission noted was the carrying of 130 RVN combat troops with a 5-man crew. A typical combination was 23 troops, 5 crewmen, a jeep, and a trailer, with about 1000 pounds of loose cargo forward (tied down with one strap). A load frequently carried internally is the 3/4-ton truck; however, now that slings are available, this load is carried externally, eliminating the airframe damage that frequently results from internal loading. It appears that the 105mm howitzer is never carried inside. Other internal loads include artillery rounds, white phosphorous, and beehives.

Restraint consensus from the trip is that "you cannot expect a crewman to put intelligent tiedowns on internal cargo loads in the field".

SAFETY

1. It was noted that passengers, troops, crew chief, and gunners do not usually employ seat belts (although in some instances gunners have been observed wearing their safety lines).

2. The 1st Cavalry Division has a full-time accident investigation board.

3. One accident investigated showed the effect of lack of equipment tiedown where movement of a mule resulted in a split fuel line and subsequent loss of the aircraft because it had to be force-landed and abandoned in a hot zone (this was a Marine CH-46 experience).

APPENDIX VI
SAMPLE COMPUTATION FOR SYSTEM EFFECTIVENESS

SAMPLE COMPUTATION

The example given below is for the Category II, System 7 (5K load limiters) with idealized floor (including 3/4-ton truck).

Notes

1. The mission was assumed to be movement of an infantry brigade (3 battalions). The distribution of the different types of loads was obtained from the "Army Infantry Reference Data - 1966", Fort Benning, Georgia.

2. Cost data were developed in Section 7.3.2.

Type of Load	No. of Loads in Brigade
1/4-ton truck (M151 type)	165
1/4-ton trailer (M100 type)	105
3/4-ton truck (M37 type)	117
Water trailer (M107 type)	12
Pallets (1,400 pounds each)	69
POL drums (4 drums per group, 1,436 pounds total)	15 groups

These items can be combined in various ways according to the type of floor and the method of restraint.

Calculation of Number of Aircraft Required

S_r = No. of sorties = 222

T_{CH} = Total cargo handling time = 12,785 minutes

R = Mission radius = 20 nautical miles

V_{cr} = Cruise speed = 150 knots

T_{cr} = Cruise time $= \dfrac{2 \times 20 \times 60}{150}$

= 16 minutes

Td = Dead time per sortie = 2 minutes

FT_r	=	Total flight time	= $(T_{cr} + Td)S_r$
			= 18 x 222
			= 3,996 minutes
T_{um}	=	Downtime due to maintenance	= 2.6 hrs per flight hour
Total downtime = 2.6 x 3,996			= 10,389 minutes
Fueling time			= 22 minutes per refueling
Nr	=	No. of sorties before fueling	= 5
Total fueling time = $\frac{222 \times 22}{55}$			= 976.8 minutes
GT	=	Ground time	= total fueling time + maintenance downtime
			= 976.8 + 10,389.0 + 12,785.0
			= 24,150.8 minutes
P_T	=	available production time per aircraft per day	= 12 hrs = 720 minutes

$$\text{No. of aircraft} = \frac{GT + FT_r}{P_T}$$

$$= \frac{24{,}150.8 + 3{,}996}{720} = 39 \text{ aircraft}$$

Utilization per aircraft = 3,996/39 = 102 minutes = 1.707 hours

Note: Fueling time includes time to move to and from the fueling area and time for refueling at 50 gallons per minute.

Calculation of Mission Cost

Investment cost of aircraft per operating day = $ 735

O & M cost per flight hour = $ 585

Mission cost = No. of aircraft x 735 + No. of aircraft x utilization per aircraft x 585 = 735 x 39 + 585 x 39 x 1.707 = $67,610

Mission cost per aircraft = $1733.6

Cost-Effectiveness Index (CEI) = No. of aircraft x mission cost per aircraft = 39 x 1,733.6 = 67,610

$$\text{Relative Cost-Effectiveness Index (RCEI)} = \frac{\text{CEI baseline}}{\text{CEI candidate}}$$

Using System 2 as a baseline,

$$\text{RCEI} = \frac{\text{System 2}}{\text{System 7}} = \frac{67{,}076}{67{,}610} = 0.99$$

Note: Tables XXXVI through XLIII represent sample computations for mission effectiveness.

TABLE XXXVI. SAMPLE CALCULATION FOR AIRCRAFT PERFORMANCE EFFECTIVENESS, IDEALIZED FLOOR TIEDOWN PATTERN

System 1				Systems 2, 7, and 7a			
Cargo Type	- X - No. of Sorties	- Y - Cargo and Passenger Weight (lb)	X Times Y	Cargo Type	- X - No. of Sorties	- Y - Cargo and Passenger Weight (lb)	X Times Y
A-1	60	3,750*	225,000	B-1	60	5,790*	347,400
A-2	105	3,440*	361,200	B-2	12	7,120*	85,440
A-3	9	3,680*	33,120	B-3	28	6,240*	174,720
A-4	3	3,716*	11,148	B-4	4	6,312*	25,248
A-5	4	4,308*	17,232	B-5	1	6,276*	6,276
				B-6	2	4,308*	8,616
Total	181	-	647,700		107	-	647,700

(*No passengers)

Performance Effectiveness of Systems 2, 7, and 7a = $\frac{181}{107}$ = 1.69

TABLE XXXVII. CATEGORY 1 SYSTEM 1, EXISTING ARMY NYLON RESTRAINT METHODS, IDEALIZED FLOOR TIEDOWN PATTERN

	1	2	3	4	5	6	7	8
					Σ(2 + 4)	Σ(3 + 4)	Σ(5 + 6)	(1 x 7)
Cargo Type	No. of Sorties	Load Time (min)	Unload Time (min)	Restraint or Release Time (min)	Load and Restraint Time (min)	Unload and Release Time (min)	Cargo Handling Time (min)	Total Cargo Handling Time (min)
A-1	60	5.33	3.83	43.5	48.83	47.33	96.16	5,770
A-2	105	16.00	11.00	35.0	51.00	46.00	97.00	10,185
A-3	9	14.83	9.33	32.5	47.33	41.83	89.16	802
A-4	3	17.50	12.00	32.0	49.50	44.00	93.50	281
A-5	4	10.50	10.50	39.0	49.50	49.50	99.00	396
Total	181	-	-	-	-	-	-	17,434

TABLE XXXVIII. CATEGORY 1 SYSTEM 2, EXPERIMENTAL 5K OR 10K LOAD LIMITERS WITH LOW-ELASTIC STRAPS, CH-47 FLOOR TIEDOWN PATTERN

	1	2	3	4	5	6	7	8
					$\Sigma(2 + 4)$	$\Sigma(3 + 4)$	$\Sigma(5 + 6)$	(1 x 7)
Cargo Type	No. of Sorties	Load Time (min)	Unload Time (min)	Restraint or Release Time (min)	Load and Restraint Time (min)	Unload and Release Time (min)	Cargo Handling Time (min)	Total Cargo Handling Time (min)
A-1	60	5.33	3.83	10.5	15.83	14.33	30.16	1,810
A-2	105	16.00	11.00	11.4	27.40	22.40	49.80	5,229
A-3	9	14.83	9.33	8.0	22.83	17.33	40.16	361
A-4	3	17.50	12.00	8.5	26.00	20.50	46.50	140
A-5	4	10.50	10.50	10.5	21.00	21.00	42.00	168
Total	181	-	-	-	-	-	-	7,708

TABLE XXXIX. CATEGORY II SYSTEM 7, INTEGRAL 5K LOAD LIMITERS WITH LOW-ELASTIC STRAPS, IDEALIZED FLOOR TIEDOWN PATTERN

	1	2	3	4	5	6	7	8
					Σ(2 + 4)	Σ(3 + 4)	Σ(5 + 6)	(1 x 7)
Cargo Type	No. of Sorties	Load Time (min)	Unload Time (min)	Restraint or Release Time (min)	Load and Restraint Time (min)	Unload and Release Time (min)	Cargo Handling Time (min)	Total Cargo Handling Time (min)
B-1	60	20.50	14.00	19.0	39.50	33.00	72.50	4,350
B-2	12	30.83	20.33	20.0	50.83	40.33	91.16	1,094
B-3	28	17.66	12.66	18.5	36.16	31.16	67.32	1,885
B-4	4	23.00	18.00	18.5	42.50	37.50	80.00	320
B-5	1	20.33	15.33	19.0	39.33	34.33	73.66	73
B-6	2	10.50	10.50	12.0	22.50	22.50	45.00	[illegible]
Total	107	-	-	-	-	-	-	7,812

TABLE XL. CATEGORY II SYSTEM 2, EXPERIMENTAL 5K AND 10K LOAD LIMITERS WITH LOW-ELASTIC STRAPS, IDEALIZED FLOOR TIEDOWN PATTERN

	1	2	3	4	5	6	7	8
					Σ(2 + 4)	Σ(3 + 4)	Σ(5 + 6)	(1 x 7)
Cargo Type	No. of Sorties	Load Time (min)	Unload Time (min)	Restraint or Release Time (min)	Load and Restraint Time (min)	Unload and Release Time (min)	Cargo Handling Time (min)	Total Cargo Handling Time (min)
B-1	60	20.50	14.00	18.9	39.40	32.90	72.30	4,350
B-2	12	30.83	20.33	19.4	50.23	39.73	89.96	1,094
B-3	28	17.66	12.66	17.4	35.06	30.06	65.12	1,885
B-4	4	23.00	18.00	18.4	41.40	36.40	77.80	312
B-5	1	20.33	15.33	17.9	38.23	33.23	71.46	72
B-6	2	10.50	10.50	10.5	21.00	21.00	42.00	84
Total	107	-	-	-	-	-	-	7,797

TABLE XLI. CATEGORY II SYSTEM 7A, INTEGRAL 7.5K LOAD LIMITERS, IDEALIZED FLOOR TIEDOWN PATTERN

	1	2	3	4	5	6	7	8
					Σ(2 + 4)	Σ(3 + 4)	Σ(5 + 6)	(1 x 7)
Cargo Type	No. of Sorties	Load Time (min)	Unload Time (min)	Restraint or Release Time (min)	Load and Restraint Time (min)	Unload and Release Time (min)	Cargo Handling Time (min)	Total Cargo Handling Time (min)
B-1	60	20.50	14.00	14.50	35.00	28.50	63.50	3,810
B-2	12	30.83	20.33	14.00	44.83	34.33	79.16	950
B-3	28	17.66	12.66	13.50	31.16	26.16	57.32	1,605
B-4	4	23.00	18.00	14.50	37.50	32.50	70.00	280
B-5	1	20.33	15.33	14.00	34.33	29.33	63.66	64
B-6	2	10.50	10.50	9.00	19.50	19.50	39.00	78
Total	107	-	-	-	-	-	-	6,787

TABLE XLII. CATEGORY II SYSTEM 7, INTEGRAL 5K LOAD LIMITERS WITH LOW-ELASTIC STRAPS, CH-47 FLOOR TIEDOWN PATTERN

	1	2	3	4	5	6	7	8
					$\Sigma(2 + 4)$	$\Sigma(3 + 4)$	$\Sigma(5 + 6)$	(1 x 7)
Cargo Type	No. of Sorties	Load Time (min)	Unload Time (min)	Restraint or Release Time (min)	Load and Restraint Time (min)	Unload and Release Time (min)	Cargo Handling Time (min)	Total Cargo Handling Time (min)
A-1	60	5.33	3.83	11.0	16.33	14.83	31.16	1,870
A-2	105	16.00	11.00	11.5	27.50	22.50	50.00	5,252
A-3	9	14.83	9.33	8.5	23.33	17.83	41.16	370
A-4	3	17.50	12.00	9.0	26.50	21.00	47.50	143
A-5	4	10.50	10.50	12.0	22.50	22.50	45.00	190
Total	181	-	-	-	-	-	-	7,813

TABLE XLIII. CATEGORY II SYSTEM 7A, INTEGRAL 7.5K LOAD LIMITERS WITH LOW-ELASTIC STRAPS, CH-47 FLOOR TIEDOWN PATTERN

	1	2	3	4	5	6	7	8
					$\Sigma(2 + 4)$	$\Sigma(3 + 4)$	$\Sigma(5 + 6)$	(1×7)
Cargo Type	No. of Sorties	Load Time (min)	Unload Time (min)	Restraint or Release Time (min)	Load and Restraint Time (min)	Unload and Release Time (min)	Cargo Handling Time (min)	Total Cargo Handling Time (min)
A-1	60	5.33	3.83	8.5	13.83	12.33	26.16	1,570
A-2	105	16.00	11.00	8.5	24.50	19.50	44.00	4,620
A-3	9	14.83	9.33	5.5	20.33	14.83	35.16	316
A-4	3	17.50	12.00	6.0	23.50	18.00	41.50	125
A-5	4	10.50	10.50	9.0	19.50	19.50	39.00	156
Total	181	-	-	-	-	-	-	6,787

APPENDIX VII
CRASH SURVIVABILITY COMPUTATION

LIST OF SYMBOLS

n'	=	peak impact g level
n	=	cargo g level
ΔV	=	impact velocity
K	=	nylon strap spring rate
g	=	acceleration of gravity, 32.2 ft/sec^2
T	=	impact pulse time duration
W	=	cargo weight
Δ	=	cargo restraint stroke
Q	=	ratio of cargo acceleration to peak impact acceleration

CALCULATION OF G LEVEL AND CARGO WEIGHT

1. Example cargo g level for development of curves in Figures 146 and 147 is calculated in the same manner as defined in the design criteria section.

2. Example cargo g level calculation for development of curves in Figures 148 and 149 is as follows:

   Given:

   70th percentile level for longitudinal impact direction
   $n' = 8.5$
   $\Delta V = 39$ fps (See dynamic design criteria.)
   $\Delta = 0.667$ (8 inches)

   Computation:

   With the use of Equation (10) from Reference 1 which is rewritten below to conform to the symbols utilized in this report and n assumed to be 5.14, then,

$$\Delta = \frac{n'gT^2}{4} - \frac{Q}{24} + \frac{Q}{2} + \frac{1}{2Q} - 1 \qquad (52)$$

$$\text{where } T^2 = {\frac{2(39)}{(8.5)(32.2)}}^{2} = 0.0814 \text{ second}$$

$$Q = \frac{5.14}{8.5} = 0.605$$

then,

$$\Delta = \frac{8.5(32.2)(0.0814)}{4} - \frac{0.605}{24} + \frac{0.605}{2}$$

$$+ \frac{1}{2(0.605)} - 1 \qquad (53)$$

or Δ is 0.667 on 8-inch stroke; therefore, n is 5.14.

3. An example of cargo weight calculation for the curves of Figures 150 and 151 is as follows:

Computation

From the above cargo g level of 5.14 at the 70th percentile level, the cargo weight for a single strap is

$\frac{5,000}{5.14}$ or 973 pounds (for 5K restraint system)

$\frac{7,500}{5.14}$ or 1,458 pounds (for 7.5K restraint system)

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) The Boeing Company, Vertol Division Boeing Center, Box 16858 Philadelphia, Pennsylvania	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Integral Helicopter Cargo Restraint System

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final technical report

5. AUTHOR(S) (Last name, first name, initial)
Shefrin, Joseph
Russo, Albert
Reichardt, William T.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
October 1969	409	52

8a. CONTRACT OR GRANT NO. DAAJ02-68-C-0038 b. PROJECT NO. 1F162203A254 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) USAAVLABS Technical Report 69-68 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) D8-2162-3

10. AVAILABILITY/LIMITATION NOTICES
This document is subject to special export controls, and each transmittal to foreign governments or foreign nationals may be made only with prior approval of US Army Aviation Materiel Laboratories, Fort Eustis, Virginia 23604.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U.S. Army Aviation Materiel Laboratories Fort Eustis, Virginia

13. ABSTRACT
Field experience with present-day helicopter cargo restraint systems has indicated that a need exists for improved cargo restraint efficiency and safety. Recent programs conducted by the Army have demonstrated that improvements in helicopter cargo restraint efficiency (reduced tiedown and release times) and safety are possible through the use of systems designed to absorb dynamic forces experienced during survivable crash conditions. A more effective cargo restraint system is possible if energy absorbing devices are integrated with present or future helicopter structures rather than applied to existing tiedown straps or floor fittings. A review of cargo restraint technology and of field practices in Vietnam and an analysis of the CH-47 helicopter cargo load support structure are presented. Analysis, selection, and evaluation of cargo restraint systems and devices indicate that a system incorporating 7,500-pound-capacity tube-ball-type load-limiting devices as an integral part of the CH-47 helicopter structure, together with low-elastic tiedown straps, will significantly improve crash survivability and cargo restraint effectiveness. A preliminary design of the proposed system, as a retrofit kit, is presented.

DD FORM 1 JAN 64 1473

Unclassified
Security Classification

Unclassified

Security Classification

14 KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Accident Survivability						
Cargo Handling in Vietnam						
Cargo Restraint (Standard and Combat)						
Cargo Tiedown Practice						
CH-47 Helicopter						
Crash Pulse Energy Absorption						
Crash Safety						
Crash Survivability						
Energy Absorbing Materials						
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